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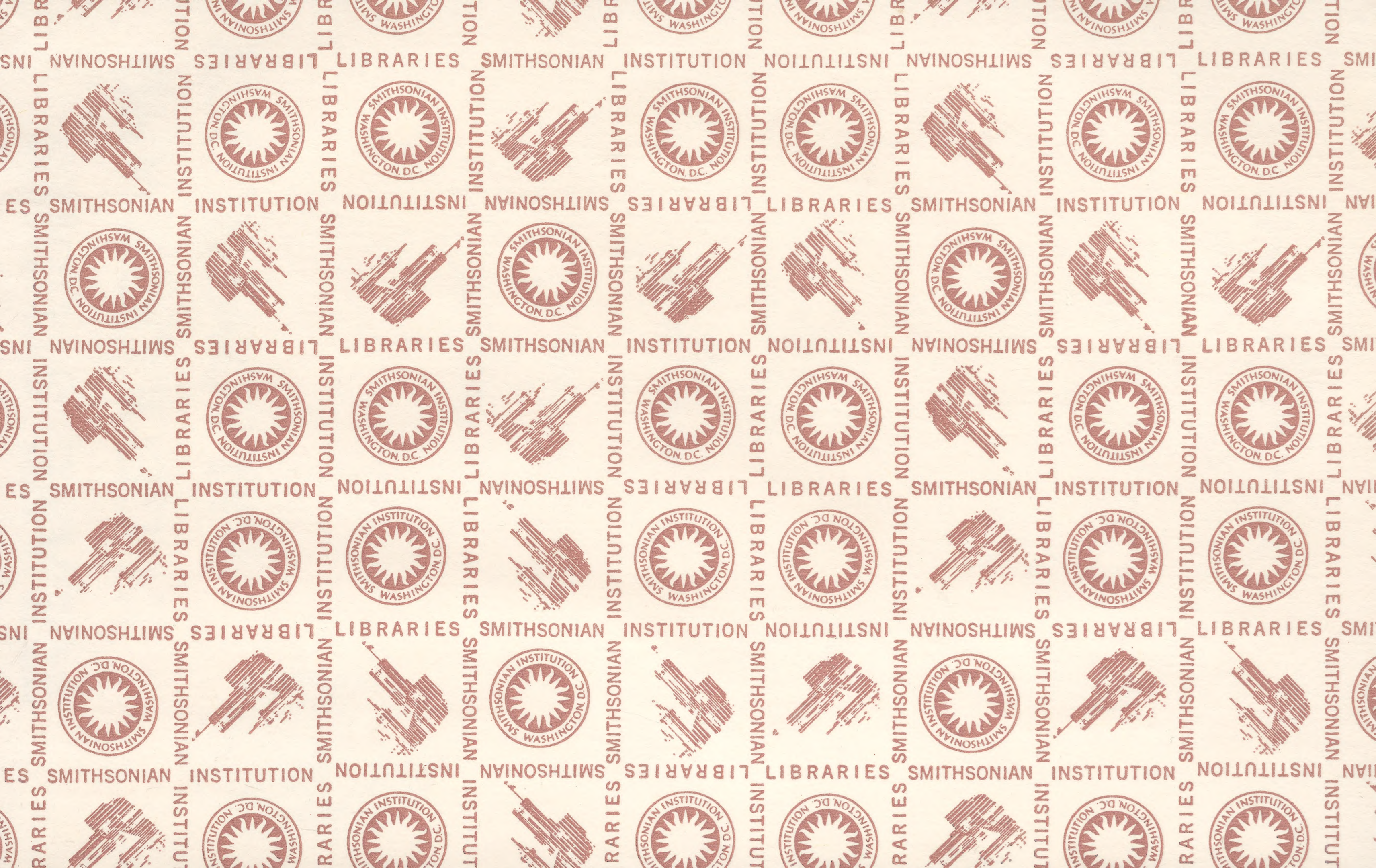
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TULANE STUDIES IN GEOLOGY AND PALEONTOLOGY

Volume 15

1979

TULANE STUDIES IN GEOLOGY AND PALEONTOLOGY

Volume 15

1979

HUBERT C. SKINNER
Editor

EMILY H. VOKES
Associate Editor

TULANE UNIVERSITY OF LOUISIANA
New Orleans

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TULANE STUDIES IN GEOLOGY AND PALEONTOLOGY

A SYMPOSIUM IN HONOR OF

KATHERINE VAN WINKLE PALMER

On the occasion of her retirement as

Director of the

PALEONTOLOGICAL RESEARCH INSTITUTION

Held at

TULANE UNIVERSITY

April 6 and 7, 1978

TULANE UNIVERSITY OF LOUISIANA

New Orleans

Katherine Van Winkle Palmer
Doctor of Science
Tulane University
April 7, 1978

Katherine Van Winkle Palmer is the retiring director of the Paleontological Research Institution. She has been affiliated with the P.R.I. since 1935, as incorporator, life trustee, vice-president, president, and for 26 years, director. Even before that time, as a graduate student under Professor G.D. Harris of Cornell University, she helped with some of the earliest issues of the *Bulletins of American Paleontology* and *Paleontographica Americana*, and until now, in her 80's, has continued to supervise the entire process of publishing these journals.

Dr. Palmer is the author of over fifty publications. Among those are: "The Veneridae of Eastern America, Cenozoic and Recent" (1972); "Gastropoda of the Claibornian Mid-Eocene of the Southern United States (1937); "The Mollusca of the Jackson Eocene of the Mississippi Embayment (Sabine River to Alabama River)" (1946); and "Catalogue of the Paleocene and Eocene Mollusca of the Southern and Eastern United States" (1965). Like all her work, each of these demonstrates her scientific ability. Her inspired solutions to paleontographic problems have made the task of subsequent workers in the area far easier.

Dr. Palmer has received numerous honors and awards, including the highest recognition of the Paleontological Society of America in 1972 and, in 1974, the award of the Western Society of Malacologists. She has also been made a member of several foreign scientific societies and many American organizations. But all the praise and recognition she has received could not be enough to match the extent of her contribution to Tertiary Paleontology. The brilliance of her work, the precision of her method, the wisdom of her leadership of the Paleontological Research Institution will stand as the greatest monument to Dr. Palmer and as the highest example for future generations of what it means to be a scientist.

Born in 1895 in Oakville, Washington, Dr. Palmer received the B.S. degree from University of Washington, and the Ph.D. from Cornell University. She is the wife of the late Dr. E. Laurence Palmer, professor of nature study, and is the mother of two sons.

Citation for honorary degree conferred upon
Dr. Palmer by Tulane University, April 7, 1978

KATHERINE VAN WINKLE PALMER

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*John Pojeta, U.S. National Museum, Washington, D.C.
Early history of the Mollusca

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Early geologists in Louisiana

*Edward B. Picou, Shell Oil Company, New Orleans
Gulf Coast Cenozoic — Model for application of stratigraphic concepts to exploration on passive margins (with Doris M. Curtis)

Harold E. Vokes, Tulane University
Observations on the genus Dimya *(Mollusca:Bivalvia) in the Cenozoic faunas of the western Atlantic region*

Katherine V. W. Palmer, Paleontological Research Institution
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Eocene and Oligocene environments and molluscan faunas of the north central Gulf Coastal Plain

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A frontier of foraminiferology — the U.S. Atlantic margin

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An overview of the terrestrial Early Tertiary of southern North America-fossil sites and Paleopedology

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Preliminary analysis of the morphometric variation in Cyclocardia granulata *(Say)*

*Douglas Lawson, University of New Orleans
The effect of biostratinomic distortion and loss of information upon the delineation and trophic analysis of ancient marine-benthonic communities

*Ronald L. Parsley, Tulane University
Hypothetical ancestral echinoderm???

*Not included in this publication

TULANE STUDIES IN GEOLOGY AND PALEONTOLOGY

Volume 15, Number 1 November 9, 1979

PLANKTIC FORAMINIFERA AND CALCAREOUS NANNOPLANKTON BIOSTRATIGRAPHY OF THE NEOGENE OF MEXICO

PART I — MIDDLE PLIOCENE

W. H. AKERS
CHEVRON U.S.A. AND TULANE UNIVERSITY

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I. ABSTRACT

Calcareous nannofossils and planktic foraminifera that are diagnostic for precise geologic ages have been identified in some marine Tertiary formations in Mexico. The original age assignments of these formations have persisted in the literature and some revisions are necessary for the Mexican sections to conform with the chronostratigraphy that has been developed for the rest of the world. New planktic evidence now affords assignment of the Mexican beds to precise trans-oceanic Neogene zones. Part I of this report is concerned with the middle Pliocene (Zone N.20) to which the following formations at designated localities are referred: Agueguexquite, Filisola, Concepcion Inferior, Concepcion Superior, and several unnamed formations. Subsequent studies will deal with the successively older formations, including the Encanto, Deposito, La Laja, Tuxpan, Guajalote, Escolin, Anahuac, Coatzintla, Meson, Alazan, and Palma Real formations.

EDITORIAL COMMITTEE FOR THIS PAPER:

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II. INTRODUCTION

The objective of this report is to document the calcareous planktic microfossils in some Pliocene formations of Mexico. Planktic foraminifera and calcareous nannoplankton have been particularly useful in understanding the chronology of depositional events in the deep seas and in many stratigraphic sections on land. The recognition of key taxa should materially assist the correlation of stratigraphic successions in the subject area with marine rocks in other parts of the world. The same fossil successions are to be seen in the Mexican Cenozoic as in other marine sequences throughout the middle and low latitudes.

Planktic foraminiferal zonations defined by Banner and Blow (1965), Blow (1969), and Berggren and Van Couvering (1974), as well as nannoplankton zones proposed by Martini (1971) are recognized in Mexico. Biostratigraphic interpretations of some of the Mexican Tertiary units with reference to standard intercontinental zonation systems have been recorded by Blow (1969), Akers (1972, 1974a, 1974b), Akers and Koeppel (1973), and Barker and Blow (1976). Recognition of planktic foraminiferal and nannoplankton zones in the Mexican succession is the basis, in turn, of correlation of these units with radiometric and chronostratigraphic time-scales, such as that proposed by Berggren and Van Couvering (1974, fig. 1).

Obviously there are advantages in using a multiplicity of faunal and floral groups for age-dating. The biostratigrapher must consider the absence of particular species in the light of both paleoecology and total ranges in geologic time, and he must be able to recognize recycled organisms. In some cases, planktic foraminifera alone were not sufficiently definitive for the purpose of assigning a formation to a precise Neogene zone and the same restrictions sometimes applied to the calcareous nannofossils. Some biostratigraphic knowledge of both planktic foraminifera and calcareous nannofossils has been useful in the zonation of the Mexican Neogene. The repudiation of former assignments does not invalidate the use of benthic organisms as guides to time but, rather, documents the incompleteness of early data relating the benthic fossils to time and facies.

Data for the present report are derived from rocks that have been referred in the literature or by geological mapping to the following formations:

Agueguexquite
Filisola
Concepcion Superior
Concepcion Inferior

In addition to the above units, material has been studied from several sequences to which rock-stratigraphic names have not been applied.

This report will deal with the formations that belong to Zone N. 20. Subsequent studies will include the Encanto, Deposito, La Laja, Tuxpan, Guajalote, Escolin, Anahuac, Coatzintla, Meson, Alazan, and Palma Real formations. The oldest rocks eventually to be included in the overall project are assignable to the Palma Real Formation, which has been referred, in part, to Zone N. 1 (Barker and Blow, 1976, text-fig. 2; p. 47). Thus, planktic foraminifera and calcareous nannoplankton will eventually be identified, illustrated, and reviewed for biostratigraphic significance for most of the Neogene Zones (N. 1 to N. 20) of the Mexican Tertiary.

It should be emphasized that the age assignments to be proposed and correlations with other formations, both in Mexico and elsewhere, are applicable only to that part of a formation as seen at the designated exposure (locality). Some formations, such as the Tuxpan, span long intervals of geologic time and represent several Neogene zones (N. 8 to N. 12). Others, such as the Agueguexquite Formation (N. 20), represent short time intervals. A complete marine depositional record does not exist at any single locality for either the entire Neogene or for the time represented by some of the formations.

The marine Neogene of Mexico is in marked contrast with the Neogene of the northern Gulf of Mexico. Surface exposures in Texas, Louisiana, and Alabama of marine beds younger than Neogene Zone 4 are of negligible extent. In Florida, marine rocks of middle Miocene age, with the exception of the Yellow River Formation, are not found at the surface (Akers, 1972, fig. 4). On the other hand, subsurface rocks of Texas and Louisiana thicken seaward and are correlatable by means of subsurface samples with the thick equivalents exposed in the Mexican Gulf Coast.

Standard methods of preparation of foraminiferal concentrations and nannofossil

slides (also stubs for the scanning electron microscope) were used. These methods are described elsewhere in the literature by the writer as well as by others. All foraminiferal samples were boiled in solutions of "Quaternary O" (see Zingula, 1968, p. 1092).

All of the fossils studied for this report were collected from outcrops by the writer, or by Dr. Harold E. Vokes and Dr. Emily H. Vokes.

III. ACKNOWLEDGMENTS

This study was made possible primarily by Harold E. Vokes and Emily H. Vokes of Tulane University. They conducted the writer to Mexico, supplied guidance in the field, and contributed numerous outcrop samples not available to the writer. In addition, discussions with them were the motivation for this project as well as the source of most of the field data. Chevron Oil Company supported the laboratory research of the writer including the use of all types of microscopes. Mr. Paul E. Koeppel and Mr. Dennis J. Greig of Chevron Oil Company are responsible for the scanning electron micrographs used in studying and illustrating the faunas and nannofloras of the formations. The writer has benefited from discussions with Mr. Barry Kohl on the relationships of beds as indicated by his map studies, particularly in the vicinity of Acayucan, Veracruz. Miss Veronica C. Catanese supplied technical assistance during the preparation of the manuscript.

IV. BIOSTRATIGRAPHY, NEOGENE ZONE 20

A. AGUEGUEXQUITE FORMATION

The Agueguexquite Formation was defined by Thalmann (1935a, p. 592; 1935b, p. 116), as follows:

> "The type locality of the Agueguexquite formation is the series of outcrops at the crossing of the road from Puerto Mexico to Santa Rosa, dipping 5° towards N. W., in the Agueguexquite Creek, 11 kms. azimuth 100° from Puerto Mexico Church (Coatzacoalcos, State of Vera Cruz, Mexico).
>
> The average thickness of this highly fossiliferous (Foraminifera and Mollusca) beds is about 200 ms. At the base, indicating a marine transgression, are layers of quartz pebbles, from hazelnut to walnut in size, which are embedded in a matrix of coarse sand and bluish-grey, micaceous, brown-weathering clay. The sediments consist principally of bluish-grey sandy clays, mostly micaceous, with intercalations of grit and sand, poorly bedded, containing a rich fauna of gastropods and lamellibranchiata and scattered plant remains, chiefly in the lower part of the formation.
>
> The geological age, judged from faunal evidences is upper Lower Miocene or lower Middle Miocene (Helvetian or Tortonian). The foraminiferal association includes over a hundred different species and is characterized by the presence of unusually large specimens of *Cuneolina* and *Textulariella*. The fauna is closely connected with that from the Choctawhatchee formation in Florida; apparently it was deposited in shallow warm water within the neritic zone.
>
> The Agueguexquite formation represents the youngest Miocene deposition as yet found in the Coatzacoalcos basin, and approximately can be correlated with the Mid-Upper Gatun formation of Panama or with the basal Bowden formation of Jamaica" (Thalmann, 1935b, p. 116).

The precise locality described by Thalmann has not been relocated and collected, but material from an exposure approximately ½ mile from the type was studied (TU 1046). The foraminiferal assemblage at TU 1046 is not so rich as that described by Thalmann for the type locality, and it may represent a different horizon of the formation. Perrilliat Montoya (1960, 1963) described mollusks from the exposure designated here as TU 1046. The beds at locality TU 638 are richly fossiliferous and have been referred to the Agueguexquite Formation by E. H. Vokes (1970 and earlier reports). It should be pointed out that the field work for this report has thus far failed to disclose foraminiferal associations characterized by the "unusually large specimens of *Cuneolina* and *Textulariella*" mentioned by Thalmann, although the number of species at TU 638 is of the order described by him. Although all of the foraminiferal associations observed in the area are representative of warm water, data on foraminiferal ecology amassed since 1935 would indicate depths greater than the neritic zone. Thalmann's description of the lithology and mollusks, however, fits the section at TU 638.

Contreras Velazquez (1956, p. 52) and Salas (1967, p. 13) have followed Thalmann in referring these beds to the Miocene. Their reasoning was based on faunal similarities in mollusks and benthic foraminifera

with the Choctawhatchee beds of Florida and the Bowden Formation of Jamaica. Subsequent studies on planktic foraminifera (Akers, 1972, p. 14-28) have shown that the Agueguexquite Formation and the Jackson Bluff Formation of the Choctawhatchee Stage are of middle Pliocene age. Studies on the calcareous nannofossils of the Agueguexquite and Jackson Bluff formations support this conclusion (Akers and Koeppel, 1973, p. 82-83). Similarly, planktic foraminifera now indicate a post-Miocene age for the Bowden Formation (Lamb and Beard, 1972, p. 31-32).

The sparse calcareous planktic assemblage at TU 1046 includes the following:

Planktic foraminifera
- *Globigerinoides quadrilobatus quadrilobatus* (d'Orbigny)
- *Globigerinoides ruber* (d'Orbigny)
- *Orbulina universa* d'Orbigny

Calcareous nannofossils
- *Ceratolithus cristatus* Kamptner
- *Discoaster brouweri* Tan Sin Hok
- *Discoaster surculus* Martini and Bramlette
- *Gephyrocapsa caribbeanica* Boudreaux and Hay
- *Pseudoemiliania lacunosa* (Kamptner)
- Reworked Eocene species

The following planktic foraminifera were identified from a dark gray clay in the lower part of an exposure in the roadcut and quarry on Mexico Highway 180, 14 miles east of the junction with the road to Coatzacoalcos, Veracruz (TU 638):
- *Globigerina bulloides apertura* Cushman
- *Globigerina bulloides bulloides* d'Orbigny
- *Globigerina juvenilis* Bolli
- *Globigerinoides obliquus extremus* Bolli and Bermúdez
- *Globigerinoides obliquus obliquus* Bolli
- *Globigerinoides quadrilobatus quadrilobatus* (d'Orbigny)
- *Globigerinoides ruber* (d'Orbigny)
- *Globorotalia (Globorotalia) cultrata limbata* (Fornasini)
- *Globorotalia (Turborotalia) acostaensis acostaensis* Blow
- *Globorotalia (Turborotalia) acostaensis humerosa* Takayanagi and Saito
- *Hastigerina (Hastigerina) siphonifera siphonifera* (d'Orbigny)
- *Orbulina universa* d'Orbigny
- *Sphaeroidinella dehiscens dehiscens* forma *immatura* (Cushman)

In the basal part of the section at TU 638, the total number of planktic specimens exceeds the total number of benthic specimens of foraminifera greater than 64 microns in size. This high ratio of planktic to benthic forms is especially interesting in view of the gravel and coarse sands that are in and interbedded with the clay component of these beds. Reworking is suggested by such an association and is further indicated by the presence of Eocene discoasters, although recycled foraminiferal tests were not seen.

Akers and Koeppel (1973, p. 83) listed and discussed the calcareous nannofossils that they identified in the Agueguexquite Formation. The list should now include the following for locality TU 638:
- *Coccolithus doronicoides* Black and Barnes
- *Cyclococcolithina leptopora* (Murray and Blackman)
- *Cyclococcolithina macintyrei* (Bukry and Bramlette)
- *Discoaster brouweri* Tan Sin Hok
- *Discoaster pentaradiatus* Tan Sin Hok
- *Discoaster surculus* Martini and Bramlette
- *Discoaster variabilis* Martini and Bramlette
- *Gephyrocapsa reticulata* Nishida
- *Helicopontosphaera kamptneri* Hay and Mohler
- *Helicopontosphaera* sp.
- *Lithostromation perdurum* Deflandre
- *Pseudoemiliania lacunosa* (Kamptner)

Geologic Age of the Agueguexquite Formation and Correlation with Other Formations.

The absence of the calcareous nannoplankton species, *Sphenolithus abies* Deflandre, may be significant in fixing the age of these beds. This species is ubiquitous in upper Miocene to middle Pliocene sediments of marine and low latitude origin. The species and also the genus became extinct during the middle Pliocene within Zone N. 20 at the approximate middle of that zone (Akers, 1974a, fig. 1). *Pseudoemiliania lacunosa* (Kamptner) does occur in the Agueguexquite beds, and it is also significant to the age of this formation, since it first appeared within Zone N. 20 (Gartner, 1969, p. 592, fig. 7; Akers, 1974a, fig. 1). *Globigerina bulloides apertura* Cushman probably ranges to the approximate middle of Zone N. 20. Blow's experience with this form was inadequate for him to fix the exact time of extinction (Blow, 1969, p. 317). Rare specimens of *Sphaeroidinella dehiscens dehiscens* forma *immatura* (Cushman) were found, but they may be pseudomorphs with arrested ontogenetic development, as described by Blow (1969, p. 336). Thus, the Agueguexquite Formation must be considered to be of middle Pliocene age, and it probably belongs just above the precise middle of Zone N. 20.

Calcareous nannoplankton indicate a close time equivalence with the following formations in the Atlantic and Gulf coasts of the United States:

Yorktown Formation at Rice's Pit, Virginia
Yorktown Formation in the Lee Creek Mine, North Carolina
Jackson Bluff Formation at Beds 4 and 10 of Alum Bluff, Florida

A slightly younger age is indicated by the calcareous nannofloras for the Agueguexquite Formation than for the Pinecrest Formation of southern Florida, the Jackson Bluff Formation at Watson's Landing and at Darling Slide, Florida. Akers and Koeppel (1973) present discussions of the calcareous nannoplankton in the Yorktown and Jackson Bluff formations, and Akers (1974a, p. 119-120) has documented the age of the Pinecrest Formation.

B. FILISOLA FORMATION

Thalmann referred the Filisola beds of the Coatzacoalcos Basin to the lower Miocene and described them as follows:

> "The upper section of the Lower Miocene shows a succession of strata of gray marl, in part strongly sandy, in places with green to blue-green clays with plant remains and Pleurotomas. Towards the top, there appears blue or greenish-gray micaceous sandstone and chalk concretions. The sandstone weathers yellowish and alternates locally with violet sand-marl. Because of the great sand content, the fossil content found in Ixhuatlan and Concepcion strata has been greatly impoverished, yet the following important species occur for the first time:
>
> *Amphistegina lessoni* d'Orbigny var.
> *Cibicides americanus* (Cushman)
> *Cristellaria vaughani* (Cushman)
> *C. rotulata* (Lamarck)
>
> Fauna and lithology permit recognition of coastal formation and sedimentation in which delta formation is already noticeable. For a time the Filisola correlates with the upper section of the Tuxpan stage (Tuxpan strata s.s.) of East Mexico" (Thalmann, 1935a, p. 592; translation by Gail P. Kohl).

Contreras Velazquez (1956, p. 54-56) has further defined the Filisola Formation and refers it to the middle Miocene (p. 48). Viniegra *et al.* (1956, p. 163) refer beds in a roadcut on the north side of Mexico Highway 180, 13 kilometers west of San Andreas Tuxtla, State of Veracruz, to the Filisola Formation. This is the same locality as stop 10 of the 20th International Geological Congress. For reasons discussed below, these beds are considered to be of middle Pliocene age. Thalmann's original description is applicable to the beds at this locality, and, in the absence of a formal designation by Thalmann or others, this locality (designated as locality TU 1141) is proposed as the type locality for the Filisola Formation.

The following planktic foraminifera were identified at TU 1141:

Globigerina bulloides apertura Cushman
Globigerinoides obliquus extremus Bolli and Bermúdez
Globigerinoides quadrilobatus quadrilobatus (d'Orbigny)
Globigerinoides ruber (d'Orbigny)
Globorotalia (Globorotalia) cultrata limbata (Fornasini)
Globorotalia (Turborotalia) acostaensis humerosa Takayanagi and Saito
Globorotalia (Turborotalia) scitula scitula (Brady)
Hastigerina (Hastigerina) siphonifera siphonifera (d'Orbigny)
Orbulina universa d'Orbigny
Prosphaeroidinella parkerae Ujiié

Calcareous nannofossils are not so abundant or well preserved in the Filisola Formation at TU 1141 as they are in other middle Pliocene assemblages of Mexico. The following identifications were confirmed by electron microscopy:

Coccolithus doronicoides Black and Barnes
Coccolithus pelagicus (Wallich)
Discoaster sp. (only fragments were observed)
Gephyrocapsa sp. cf. *G. reticulata* Nishida
Helicopontosphaera sp.
Reticulofenestra pseudoumbilica (Gartner)
Reworked nannofossils of Eocene age

The following species were identified by light microscopy but were not observed in preparations for electron microscopy:

Gephyrocapsa caribbeanica Boudreaux and Hay
Pseudoemiliania lacunosa (Kamptner)
Sphenolithus abies Deflandre (heavily calcified)

Geologic Age of the Filisola Formation and Correlation with Other Formations.

The conjunction of *Globigerina bulloides apertura* Cushman, *Sphenolithus abies* Deflandre, *Gephyrocapsa caribbeanica* Boudreaux and Hay, and *Pseudoemiliania lacunosa* (Kamptner) fixes the age of the Filisola Formation at the proposed type locality as middle Pliocene, Neogene Zone 20 (Akers, 1974, fig. 1). The absence of *Sphenolithus abies* Deflandre in the Agueguexquite Formation (also Zone N. 20) indicates

that the Aquequexquite Formation is stratigraphically higher than the Filisola Formation. In general, this relationship has been known by many Mexican geologists, although the precise age of the two formations has not been determined previously.

Nannoplankton floras indicate that the Filisola Formation was deposited contemporaneously with the Jackson Bluff Formation, *Ecphora* Faunizone, at Watson's Landing and at Darling Slide, northern Florida. The Filisola Formation is also contemporaneous with the Pinecrest Formation of southern Florida. The Filisola Formation, then, is slightly older than the Jackson Bluff Formation at beds 4 and 10 of Alum Bluff, Florida. It is also slightly older than the Yorktown Formation at Rice's Pit, Virginia, and the Yorktown Formation at Lee Creek Mine, North Carolina. These slightly older beds contain *Sphenolithus abies,* as does the Filisola Formation at the proposed type locality (see Akers and Koeppel, 1973, for a discussion of the calcareous nannoplankton of these formations).

C. CONCEPCION FORMATION

Thalmann (1935a, p. 592) described the Concepcion Formation as follows:

> "These middle Lower Miocene deposits also have an especially rich, small foraminiferal fauna. Lithologically we are dealing here primarily with a blue-gray marl and clay with sand lenses, chalk concretions, and rich *Pleurotoma* fauna in the upper part. The weathered color of the marl is mostly brownish. Index fossils are:
>
> *Cibicides filisolaensis* Nuttall
> *Chilostomella mexicana* Nuttall
> *Bolivina subaenariensis* Cushm.
> *Epistomina elegans* d'Orb.
> *Gyroidina soldanii* d'Orb.
> *Marginulina pecketi* Schrodt
> *M. pecketi* var. *spinosa* Schrodt
> *M. hirsuta* d'Orb. var.
> *Nodosaria hispida* d'Orb.
> *Siphogenerina transversa* Cushm.
> *Textularia mississippiensis* Cushm.
>
> Facies: deeper neritic zone to shallower bathyal region *(Pleurotoma* clay) in the sense of L. Strausz. In age, it agrees with the strata series of the Papantla strata of the Tuxpan Stage of East Mexico (Burdigalian to older Vindobonian)".

Thalmann did not specify a type locality for the Concepcion Formation. The type area (type depositional basin), as for the Agueguexquite Formation, is "the southeastern part of Mexico, especially in the Coatzacoalcos Basin on the Atlantic side of the Isthmus of Tehuantepec" (Thalmann, 1935a, p. 592, as translated by Gail P. Kohl).

Subsequent to Thalmann's observations, subsurface beds in this area have been referred to the "Concepcion Inferior" and the "Concepcion Superior" formations by industrial micropaleontologists. Although no clear lithological basis has been offered for this subdivision, or, indeed, for the separation of the Concepcion from the Aqueuexquite Formation, the Concepcion Inferior and the Concepcion Superior are said to be recognized by characteristic suites of benthic foraminifera (Sansores and Flores-Covarrubias, 1972, vol. 1, p. 5; Contreras Velazquez, 1956, p. 56-59).

Contreras Velazquez *et al.* (1956, p. 176) designated the exposure at stop 5 of the 20th International Geological Congress Excursion C-7 as Concepcion Inferior. This is TU 1025 of Vokes (1970, p. 49) who described the locality as follows:

> "Concepcion Fm., roadcut on east side of road from Nuevo Teapa to Ixhuatlan, 0.5 mile south of junction with Mexico Highway 180, Veracruz, Mexico."

Material collected by the writer in May, 1972, from this locality contains the following planktic foraminifera:

Biorbulina bilobata (d'Orbigny)
Candeina nitida nitida d'Orbigny
Globigerina bulloides bulloides d'Orbigny
Globigerinita uvula (Ehrenberg)
Globigerinoides conglobatus conglobatus (Brady)
Globigerinoides obliquus extremus Bolli and Bermúdez
Globigerinoides obliquus obliquus Bolli
Globigerinoides quadrilobatus quadrilobatus (d'Orbigny)
Globigerinoides quadrilobatus sacculifer (Brady)
Globigerinoides ruber (d'Orbigny)
Globoquadrina altispira altispira (Cushman and Jarvis)
Globoquadrina altispira globosa Bolli
Globoquadrina conglomerata (Schwager)
Globoquadrina venezuelana (Hedberg)
Globorotalia (Globorotalia) crassula conomiozea Kennett
Globorotalia (Globorotalia) cultrata limbata (Fornasini)
Globorotalia (Globorotalia) margaritae Bolli and Bermúdez
Globorotalia (Turborotalia) acostaensis humerosa Takayanagi and Saito
Globorotalia (Turborotalia) acostaensis pseudopima Blow
Hastigerina (Hastigerina) siphonifera siphonifera (d'Orbigny)

Orbulina universa d'Orbigny
Sphaeroidinellopsis subdehiscens subdehiscens (Blow)

The calcareous nannofossils at TU 1025 have been illustrated and discussed in a previous publication (Akers and Koeppel, 1973, p. 82, pl. 1, 3). The following species have been identified:

Ceratolithus cristatus Kamptner
Discoaster asymmetricus Gartner
Discoaster brouweri Tan Sin Hok
Discoaster pentaradiatus Tan Sin Hok
Discoaster surculus Martini and Bramlette
Discoaster variabilis Martini and Bramlette
Pseudoemiliania lacunosa (Kamptner)
Reticulofenestra pseudoumbilica (Gartner)
Sphenolithus abies Deflandre

Geologic Age of the Concepcion Inferior Beds at TU 1025 and Correlation with Other Formations

Both Contreras Velazquez (1956, p. 48) and Sansores and Flores-Covarrubias (1972, p. 4) perpetuate the older concept of an early Miocene age for the Concepcion Inferior beds. This concept was proposed without benefit of our present information on planktic biostratigraphy. Both planktic foraminifera and calcareous nannoplankton indicate a younger age for these strata than that proposed by earlier investigators.

The concurrence of *Globorotalia (Turborotalia) acostaensis pseudopima* Blow, *Reticulofenestra pseudoumbilica* (Gartner), *Pseudoemiliana lacunosa* (Kamptner), and *Sphenolithus abies* Deflandre dates the Concepcion Inferior beds at TU 1025 as middle Pliocene Zone N. 20. This association is also evidence that deposition here was precisely contemporaneous with the Filisola Formation at the proposed type locality (TU 1141), the Pinecrest Formation in southern Florida, the Jackson Bluff Formation, *Ecphora* Faunizone, at Watson's Landing and at Darling Slide, Florida. The Concepcion Inferior strata, then, like the Filisola Formation, is slightly older than the Jackson Bluff Formation at beds 4 and 10 of Alum Bluff, Florida, the Yorktown Formation at Rice's Pit, Virginia, and the Yorktown Formation at Lee Creek Mine, North Carolina (see Akers and Koeppel, 1973, for a discussion of the calcareous nannoplankton in these formations).

The Concepcion Superior Formation is represented in a road metal quarry (State of Veracruz) on Mexico Highway 175, about one mile north of the bridge over the Tonto River (just above confluence with the Papaloapan River), near Tuxtepec, Oaxaca, Mexico (Contreras Velazquez, 1956, p. 56-58). The locality is designated in this report as TU 1026. The general lithologic aspect and the profusion of megafossils in the rocks are so reminiscent of the Chipola Formation of northwestern Florida that one wonders if the superficial similarities were not influential in the early assignment of the Concepcion beds to the Miocene. The benthic genus *Amphistegina*, moreover, is conspicuous in both formations. The microplankton of the two formations, however, are quite different (see Akers, 1972, p. 9-12, for the Chipola Formation), as are most of the benthic foraminifera.

The following planktic foraminifera have been identified in the Concepcion Superior beds at TU 1026:

Biorbulina bilobata (d'Orbigny)
Globigerina bulloides bulloides d'Orbigny
Globigerina nepenthes Todd
Globigerinita uvula (Ehrenberg)
Globigerinoides conglobatus conglobatus (Brady)
Globigerinoides obliquus extremus Bolli and Bermúdez
Globigerinoides obliquus obliquus Bolli
Globigerinoides quadrilobatus quadrilobatus (d'Orbigny)
Globigerinoides quadrilobatus sacculifer (Brady)
Globigerinoides ruber (d'Orbigny)
Globoquadrina altispira globosa Bolli
Globorotalia (Globorotalia) cultrata limbata (Fornasini)
Globorotalia (Globorotalia) margaritae Bolli and Bermúdez
Globorotalia (Globorotalia) cf. *Globorotalia multicamerata* Cushman and Jarvis
Globorotalia (Turborotalia) acostaensis humerosa Takayanagi and Saito
Hastigerina (Hastigerina) siphonifera siphonifera (d'Orbigny)
Orbulina universa d'Orbigny
Sphaeroidinellopsis subdehiscens subdehiscens (Blow)

The calcareous nannofossils at locality TU 1026 have been illustrated and discussed in a previous publication (Akers and Koeppel, 1973, p. 82-83, pl. 1, 3, 4). The following species have been identified here:

Cyclococcolithina leptopora (Murray and Blackman)
Cyclococcolithina macintyrei (Bukry and Bramlette)
Discoaster brouweri Tan Sin Hok

Discoaster pentaradiatus Tan Sin Hok
Discoaster surculus Martini and Bramlette
Pseudoemiliania lacunosa (Kamptner)
Reticulofenestra pseudoumbilica (Gartner)
Sphenolithus abies Deflandre

Geologic Age of the Concepcion Superior Formation at TU 1026 and Correlation with Other Formations

The concurrence of *Pseudoemiliania lacunosa* (Kamptner), *Reticulofenestra pseudoumbilica* (Gartner), and *Sphenolithus abies* Deflandre in the Concepcion Superior Formation at TU 1026 fixes the age as middle Pliocene Zone N. 20. Little, if any, difference in age can be shown for the Concepcion Inferior beds at TU 1025 and the Concepcion Superior strata at TU 1026, and the same relationships described above for the Concepcion Inferior Formation at TU 1025 with other formations would apply equally for the Concepcion Superior locality at TU 1026.

D. UNNAMED FORMATIONS

Microfossils of middle Pliocene age were collected from two localities (TU 1083 and TU 1136) for which the rock stratigraphic nomenclature is not clear. Whether such beds can be assigned correctly to an existing formally designated unit must be determined by lithologic study in the field. The outcrops fall within areas designated on published maps as "lower Miocene" and "upper Miocene" (Contreras Velazquez *et al.*, 1956, fig. 21).

Locality TU 1083.

These beds are exposed in a roadcut on Mexico Highway 185, 3.0 miles north of Sayula, State of Veracruz, Mexico. The locality is within an area designated as "lower Miocene" on map 21 of Excursion C-7, Congreso Geologico Internacional (Contreras Velazquez *et al.*, 1956, map 21). The Concepcion Inferior Formation as designated by Contreras Velazquez *et al.*, (1956, p. 176) at stop 5 of the 20th International Geological Congress also falls within the area indicated by map legend as "lower Miocene." Stop 5 (TU 1025) is approximately 80 kilometers east of TU 1083.

Hand samples from this formation are marked by a profusion of echinoid spines. The planktic microfauna and microflora, however, are extremely rich. Calcareous nannoplankton from the locality were discussed by Akers and Koeppel (1973, p. 83), and the beds were referred to Zone N. 20.

The following planktic foraminifera were identified at TU 1083:

Biorbulina bilobata (d'Orbigny)
Globigerina bulloides bulloides d'Orbigny
Globigerinita uvula (Ehrenberg)
Globigerinoides conglobatus conglobatus (Brady)
Globigerinoides obliquus extremus Bolli and Bermúdez
Globigerinoides obliquus obliquus Bolli
Globigerinoides quadrilobatus sacculifer (Brady)
Globoquadrina altispira altispira (Cushman and Jarvis)
Globoquadrina altispira globosa Bolli
Globoquadrina venezuelana (Hedberg)
Globorotalia (Globorotalia) cultrata menardii (Parker, Jones and Brady)
Globorotalia (Globorotalia) margaritae Bolli and Bermúdez
Globorotalia (Turborotalia) acostaensis humerosa Takayanagi and Saito
Globorotalia (Turborotalia) crassacrotonensis Conato and Follador
Hastigerina (Hastigerina) siphonifera siphonifera (d'Orbigny)
Orbulina universa d'Orbigny
Prosphaeroidinella parkerae Ujiié
Sphaeroidinellopsis subdehiscens subdehiscens (Blow)

The calcareous nannoplankton at locality TU 1083 were illustrated and reviewed by Akers and Koeppel (1973, p. 83) and were useful in the precise dating of the formation. The following species were identified:

Ceratolithus rugosus Bukry and Bramlette
Coccolithus doronicoides Black and Barnes
Coccolithus pelagicus (Wallich)
Cristallolithus multiporus (Kamptner)
Cyclococcolithina leptopora (Murray and Blackman)
Cyclococcolithina macintyrei (Bukry and Bramlette)
Discoaster asymmetricus Gartner
Discoaster brouweri Tan Sin Hok
Discoaster exilis Martini and Bramlette
Discoaster pentaradiatus Tan Sin Hok
Discoaster perplexus Bramlette and Riedel
Discoaster surculus Martini and Bramlette
Discoaster variabilis Martini and Bramlette
Emiliania annula (Cohen)
Gephyrocapsa caribbeanica Boudreaux and Hay
Helicopontosphaera kamptneri Hay and Mohler
Pontosphaera sp.
Pseudoemiliania lacunosa (Kamptner)
Reticulofenestra pseudoumbilica (Gartner)
Sphenolithus abies Deflandre
Umbilicosphaera mirabilis (Lohmann)

Geologic Age of the Beds at TU 1083

These species constitute a typical Pliocene nannoflora, and their overlapping stratigraphic ranges indicate a precise position for the beds at TU 1083 in Zone N. 20. *Sphenolithus abies* Deflandre and *Reticulofenestra pseudoumbilica* (Gartner) indicate that the age cannot be younger than Zone N. 20. *Pseudoemiliania lacunosa* (Kamptner) and *Gephyrocapsa caribbeanica* Boudreaux and Hay establish an age no older than Zone N. 20.

Locality TU 1136

Beds are exposed in a roadcut at K 15 on Mexico Highway 185, south of Acayucan, State of Veracruz. The locality lies within an area designated as "middle Miocene" on Excursion C-7, Congreso Geologico Internacional (Contreras Velazquez *et al.*, 1956, fig. 21).

The following planktic foraminifera were identified at TU 1136:

Biorbulina bilobata (d'Orbigny)
Globigerina bulloides bulloides d'Orbigny
Globigerina calida praecalida Blow
Globigerina decoraperta Takayanagi and Saito
Globigerinoides obliquus extremus Bolli and Bermúdez
Globigerinoides obliquus obliquus Bolli
Globigerinoides quadrilobatus sacculifer (Brady)
Globorotalia (Globorotalia) cultrata menardii (Parker, Jones and Brady)
Globorotalia (Turborotalia) acostaensis humerosa Takayanagi and Saito
Orbulina universa d'Orbigny
Prosphaeroidinella parkerae Ujiié

The following calcareous nannofossils were identified at TU 1136 by scanning electron microscopy:

Coccolithus pelagicus (Wallich)
Cristallolithus macroporus (Deflandre)
Cyclococcolithina macintyrei (Bukry and Bramlette)
Discoaster brouweri Tan Sin Hok
Discoaster pentaradiatus Tan Sin Hok
Discoaster perplexus Bramlette and Riedel
Discoaster variabilis Martini and Bramlette
Gephyrocapsa reticulata Nishida
Helicopontosphaera sp.
Lithostromation perdurum Deflandre
Pseudoemiliania lacunosa (Kamptner)
Reticulofenestra pseudoumbilica (Gartner)
Sphenolithus abies Deflandre

Geologic Age of the Beds at TU 1136

The overlapping ranges of *Pseudoemiliania lacunosa* (Kamptner) with *Reticulofenestra pseudoumbilica* (Gartner) and *Sphenolithus abies* Deflandre fix the age of this formation within Zone N. 20.

Correlation of the Unnamed Formation(s) at TU 1083 and TU 1136 with Other Formations

Sphenolithus abies Deflandre and *Reticulofenestra pseudoumbilica* (Gartner) occur at both of these localities. These species become extinct within Zone N. 20. The occurrence of these species with other species, such as *Gephyrocapsa caribbeanica* Boudreaux and Hay and *Pseudoemiliania lacunosa* (Kamptner) that are known to have their first evolutionary occurrence within Zone N. 20, would seem to offer a reliable basis for the correlation of the formations wherein such a concurrence is observed (Akers, 1974, fig. 1). On this premise, the unnamed formation(s) at TU 1083 and TU 1136 would be precisely contemporaneous with the Concepcion Inferior Formation at TU 1025, the Concepcion Superior Formation at TU 1026, the Filisola Formation at TU 1141, the Jackson Bluff Formation at Watson's Landing and Darling Slide, northern Florida, and the Pinecrest Formation in southern Florida.

All of the above formations are approximately correlatable with the Agueguexquite Formation at TU 638 and TU 1046, the Yorktown Formation at Rice's Pit, Virginia, and at Lee Creek Mine, North Carolina, and the Jackson Bluff Formation, beds 4 and 10 of Alum Bluff, northern Florida. The absence of the ubiquitous species, *Sphenolithus abies* Deflandre and *Reticulofenestra pseudoumbilica* (Gartner), suggests that this latter group of formations, though also referable to Zone N. 20 by the association of other species (Akers and Koeppel, 1973, p. 80-83), are slightly younger than the former group.

V. TAXONOMY

The taxonomic concept adopted for this series of reports is similar to that followed by Thierstein (1976, p. 348-353) in which age dating and correlations in geologic time are the main objectives. This section presents the planktic foraminifera and the calcareous nannofossils in separate groups and alphabetically by specific epithet in each respective group. References to original descriptions, subsequent combinations, and

synonyms are given. Remarks are included when pertinent. Additional references for the calcareous nannofossils may be found in Loeblich and Tappan (1966, 1968, 1969, 1970a, 1970b, 1971, 1973). The plates for this report are organized alphabetically by genus, space permitting, in order to facilitate comparison of similar forms. The species lists for the various formations are also arranged alphabetically by genus. The plate and figure references immediately following each author's name in the following alphabetized list of specific or subspecific epithets are to the illustrations in this study.

A. PLANKTIC FORAMINIFERA

Globorotalia (Turborotalia) acostaensis acostaensis Blow. Pl. 4, fig. 11

Globorotalia acostaensis BLOW, 1959, Bull. Amer. Paleontology, vol. 39, no. 178, p. 208-210, pl. 17, fig. 106a-c, 107.
Globoquadrina acostaensis (Blow), PARKER, 1967, Bull. Amer. Paleontology, vol. 52, no. 235, p. 164-165, pl. 24, fig. 3-9.
Globorotalia (Turborotalia) acostaensis acostaensis Blow, BLOW, 1969, Proc. First International Conference on Planktonic Microfossils, vol. 1, p. 344-345, pl. 9, fig. 13-15; pl. 33, fig. 1, 2.

Globorotalia (Turborotalia) acostaensis humerosa Takayanagi and Saito. Pl. 5, fig. 1, 6

Globorotalia humerosa TAKAYANAGI and SAITO, 1962, Sci. Repts., Tohoku Univ., ser. 2 (Geology), Spec. Vol. no. 5, p. 78, pl. 28, fig. 1, 2.
Globoquadrina humerosa (Takayanagi and Saito), PARKER, 1967, Bull. Amer. Paleontology, vol. 52, no. 235, p. 169-170, pl. 24, fig. 10, 11; pl. 25, fig. 1-6.
Globorotalia (Turborotalia) acostaensis humerosa Takayanagi and Saito, BLOW, 1969, Proc. First International Conference on Planktonic Microfossils, vol. 1, p. 345-346, pl. 33, fig. 3-9; pl. 34, fig. 1-3.

Globorotalia (Turborotalia) acostaensis pseudopima Blow. Pl. 5, fig. 3

Globorotalia (Turborotalia) acostaensis pseudopima BLOW, 1969, Proc. First International Conference on Planktonic Microfossils, vol. 1, p. 387-388, pl. 35, fig. 1-7.

Globoquadrina altispira altispira (Cushman and Jarvis). Pl. 3, fig. 8

Globigerina altispira CUSHMAN and JARVIS, 1936, Cushman Lab. Foram. Res., Contr., vol. 12, pt. 1, p. 5, pl. 1, fig. 13a-c, 14.
Globoquadrina altispira altispira (Cushman and Jarvis), BOLLI, 1957, U. S. Natl. Mus., Bull. 215, p. 111, pl. 24, fig. 7a-8b.

Globoquadrina altispira globosa Bolli. Pl. 3, fig. 10

Globoquadrina altispira globosa BOLLI, 1957, U. S. Natl. Mus., Bull. 215, p. 111, pl. 24, fig. 9, 10.

Biorbulina bilobata (d'Orbigny). Pl. 2, fig. 1

Globigerina bilobata D'ORBIGNY, 1846, Foraminifères du bassin tertiaire de Vienne, p. 164, pl. 9, fig. 11-14.
Orbulina bilobata (d'Orbigny), PALMER, 1941, Mem. Soc. Cubana Hist. Nat., vol. 15, p. 286, pl. 28, fig. 3.
Biorbulina bilobata (d'Orbigny), BLOW, 1956, Micropaleontology, vol. 2, no. 1, p. 69-70, text-fig. 2, no. 16.

Globigerina bulloides apertura Cushman. Pl. 2, fig. 2-3.

Globigerina apertura CUSHMAN, 1918, U. S. Geol. Surv., Bull. 676, p. 57, pl. 12, fig. 8a-c.
Globigerina riveroae BOLLI and BERMÚDEZ, 1965, Bol. Informativo, Asociacion Venezolana de Geologia, Min. y Pet., vol. 8, no. 5, p. 137, 138, pl. 1, fig. 1-6.
Globigerina bulloides apertura Cushman, BLOW, 1969, Proc. First International Conference on Planktonic Microfossils, vol. 1, p. 317, pl. 12, fig. 8.

Remarks: Some of the specimens from the Agueguexquite Formation (pl. 2, fig. 2, 3) resemble *Globigerinoides obliquus obliquus* Bolli. However, close examination does not disclose supplementary apertures.

Globigerina bulloides bulloides d'Orbigny. Pl. 2, fig. 4-6

"Polymorphium tuberosum et globiferum" SOLDANI, 1791 (part), Testaceogr. ac Zoophytogr., vol. 1, pt. 2, p. 117, pl. 123, fig. 0 (not figs. H, I, and P, *fide* Banner and Blow, 1960, p. 3).
Globigerina bulloides D'ORBIGNY, 1826, Ann. Sci. Nat., (ser. 1) vol. 7, p. 277, list no. 1.
Globigerina bulloides bulloides d'Orbigny, BLOW, 1969, Proc. First International Conference on Planktonic Microfossils, vol. 1, p. 316-317, pl. 14, fig. 1, 2.

Globigerina calida praecalida Blow. Pl. 2, fig. 7

Globigerina calida PARKER, 1962, *partim*, Micropaleontology, vol. 8, no. 2, p. 221, pl. 1, fig. 12 (not pl. 1, fig. 9a-c, 10a-b, 11).
Globigerina calida PARKER, 1967, *partim*, Bull. Amer. Paleontology, vol. 52, no. 235, pl. 18, fig. 6a-c, 7, 8a-b, 9, 10 (not fig. 11, ? 12).
Globigerina calida praecalida BLOW, 1969, Proc. First International Conference on Planktonic Microfossils, vol. 1, p. 380-381, pl. 13, fig. 6, 7; pl. 14, fig. 3.

Globigerinoides conglobatus conglobatus (Brady). Pl. 2, fig. 10
Globigerina conglobata BRADY, 1879, Quart. Jour. Micr. Science, (new ser.) vol. 19, p. 286.
Globigerinoides conglobatus (Brady), PARKER, 1962, Micropaleontology, vol. 8, no. 2, p. 229, pl. 3, fig. 1-5.
Globigerinoides conglobatus conglobatus (Brady), AKERS, 1972, Tulane Stud. Geol. Paleont., vol. 9, no. 1-4, p. 56, 58, pl. 24, fig. 1, 2; pl. 58, fig. 1, 2.

Globoquadrina conglomerata (Schwager). Pl. 3, fig. 9
Globigerina conglomerata SCHWAGER, 1866, *Novara* Exped. 1857-1859, Geol. Theil., vol. 2, pt. 2, p. 255, pl. 7, fig. 113.
Globoquadrina conglomerata (Schwager), PARKER, 1967, Bull. Amer. Paleontology, vol. 52, no. 235, p. 165-166, pl. 27, fig. 4.

Globorotalia (Turborotalia) crassacrotonensis Conato and Follador. Pl. 5, fig. 2
Globorotalia crassacrotonensis CONATO and FOLLADOR, 1967, Bol. Soc. Geol. Italy, vol. 86, p. 557-558, fig. 2a-c; fig. 4, no. 3.

Globorotalia (Globorotalia) crassula conomiozea Kennett. Pl. 4, fig. 2
Globorotalia conomiozea KENNETT, 1966, Micropaleontology, vol. 12, p. 235, pl. 1, fig. 8-18, pl. 2, fig. 6-13; text-fig. 10.
Globorotalia (Globorotalia) crassula conomiozea Kennett, BLOW, 1969 Proc. First International Conference on Planktonic Microfossils, vol. 1, p. 360-361, pl. 41, fig. 5-8.

Globorotalia (Globorotalia) cultrata limbata (Fornasini). Pl. 4, fig. 3
Rotalia limbata D'ORBIGNY, 1826, Tableau Méthodique de la classe des Céphalopodes, Ann. Sci. Nat., vol. 7, p. 274, list no. 30.
Nomen nudum.
Rotalia limbata D'ORBIGNY, *in* FORNASINI, 1902, R. Accad. Sci., Ist. Bologna, Mem. Sci. Nat., Bologna, (ser. 5) vol. 10, p. 56, text-fig. 55.
Globorotalia pseudomiocenica BOLLI and BERMÚDEZ, 1965, Bol. Informativo, Assoc. Venezolana de Geol., Min. y Pet., vol. 8, no. 5, p. 140-141, pl. 1, fig. 13-15.
Globorotalia (Globorotalia) cultrata limbata (Fornasini), BLOW, 1969, Proc. First International Conference on Planktonic Microfossils, vol. 1, p. 359, pl. 7, fig. 4-6; pl. 42, fig. 2, 3.

Globorotalia (Globorotalia) cultrata menardii (Parker, Jones and Brady). Pl. 4, fig. 4-5, 9
Rotalia menardii PARKER, JONES and BRADY, 1865, Ann. Mag. Nat. Hist., (ser. 3) vol. 16, p. 20, pl. 3, fig. 81.
Globorotalia (Globorotalia) cultrata menardii (Parker, Jones and Brady), BLOW, 1969, Proc. First International Conference on Planktonic Microfossils, vol. 1, p. 359-360, pl. 6, fig. 9-11.

Globigerina decoraperta Takayanagi and Saito. Pl. 2, fig. 8
Globigerina druryi Akers *decoraperta* TAKAYANAGI and SAITO, 1962, Sci. Repts. Tohoku Univ., ser. 2 (Geology), Spec. Vol. no. 5, p. 85, pl. 28, fig. 10.
Globigerina decoraperta Takayanagi and Saito, PARKER, 1967, Bull. Amer. Paleontology, vol. 52, no. 235, p. 149, pl. 19, fig. 1a-c (not fig. 2).

Sphaeroidinella dehiscens dehiscens forma *immatura* (Cushman). Pl. 5, fig. 7
Sphaeroidina dehiscens Parker and Jones var. *immatura* CUSHMAN, 1919, Carnegie Inst. Washington, Publ. no. 291, p. 40, pl. 14, fig. 2.
Sphaeroidinella dehiscens dehiscens forma *immatura* (Cushman), BLOW, 1969, Proc. First International Conference on Planktonic Microfossils, vol. 1, p. 336, pl. 29, fig. 6-8.

Remarks: The specimens referred here may be pseudomorphs with arrested ontogenetic development, as described by Blow (1969, p. 336).

Globigerina juvenilis Bolli. Pl. 1, fig. 3
Globigerina juvenilis BOLLI, 1957, U.S. Natl. Mus., Bull. 215, p. 110, pl. 24, fig. 5a-6.

Globorotalia (Globorotalia) margaritae Bolli and Bermúdez. Pl. 4, fig. 6-8
Globorotalia margaritae BOLLI and BERMÚDEZ, 1965, Bol. Informativo, Asociacion Venezolana de Geologia, Min. y Pet., vol. 8, no. 5, p. 139-140, pl. 1, fig. 16-18.

Globorotalia (Globorotalia) cf. *Globorotalia multicamerata* Cushman and Jarvis. Pl. 4, fig. 10
Globorotalia menardii (d'Orbigny) var. *multicamerata* CUSHMAN and JARVIS, 1930, Jour. Paleontology, vol. 4, p. 367, pl. 34, fig. 8.

Remarks: The specimen figured in this report has fewer chambers than typical forms.

Globigerina nepenthes Todd. Pl. 1, fig. 2
Globigerina nepenthes TODD, 1957, U.S. Geol. Survey, Prof. Paper 280-H, p. 301, pl. 78, fig. 7a-b.
Sphaeroidinellopsis nepenthes (Todd) var. *constricta* BERMÚDEZ, 1961, Mem. III Congr. Geol. Venezolano, vol. 3, Bol. Geol. Publ. Esp. 3, (1960), p. 1278, pl. 10, fig. 2a-b.

Candeina nitida nitida d'Orbigny, Pl. 1, fig. 1
Candeina nitida D'ORBIGNY, 1839, Foraminifères, *in* DE LA SAGRA, Hist. Phys. Pol. Cuba, p. 108, pl. 2, fig. 27-28.

Candeina nitida nitida d'Orbigny, BLOW, 1969, Proc. First International Conference on Planktonic Microfossils, vol. 1, p. 335, pl. 23, fig. 1-4.

Globigerinoides obliquus extremus Bolli and Bermúdez. Pl. 3, fig. 1

Globigerinoides obliquus extremus BOLLI and BERMÚDEZ, 1965, Bol. Informativo, Assoc. Venezolana de Geol., Min. y Pet., vol. 8, no. 5, p. 139, pl. 1, fig. 10-12.

Globigerinoides obliquus obliquus Bolli. Pl. 3, fig. 2-3

Globigerinoides obliqua BOLLI, 1957, U. S. Natl. Mus., Bull. 215, p. 113, pl. 25, fig. 9, 10, text-fig. 21, no. 5.

Globigerinoides obliquus obliquus Bolli, BLOW, 1969, Proc. First International Conference on Planktonic Microfossils, vol. 1, p. 324.

Prosphaeroidinella parkerae Ujiié. Pl. 5, fig. 8

Sphaeroidinella disjuncta Finlay, TODD, 1964, U.S. Geol. Surv., Prof. Paper 260-CC, p. 1089, pl. 290, fig. 2, 4.

Sphaeroidinella seminulina (Schwager), PARKER, 1967, Bull. Amer. Paleontology, vol. 52, no. 235, p. 161-162, pl. 23, fig. 3, 5 (not 1, 2, 4).

Sphaeroidinellopsis subdehiscens subdehiscens Blow, AKERS, 1972, Tulane Stud. Geol. Paleont., vol. 9, no. 1-4, p. 86, pl. 20, fig. 2-4; pl. 34, fig. 2; pl. 35, fig. 3-4; pl. 39, fig. 1, 3; pl. 49, fig. 3.

Prosphaeroidinella parkerae UJIIÉ, 1976, Bull. Natl. Sci. Mus., ser. C (Geol.), vol. 2, no. 1, p. 14-19, pl. 3, fig. 4; pl. 4, fig. 1, 2, 4; pl. 5, fig. 1-4; pl. 12, fig. 5; pl. 13, fig. 1.

Globigerinoides quadrilobatus quadrilobatus (d'Orbigny). Pl. 3, fig. 4

Globigerina quadrilobata D'ORBIGNY, 1846, Foraminifères fossiles du bassin tertiaire de Vienne, p. 164, pl. 9, fig. 7-10.

Globigerinoides quadrilobatus quadrilobatus (d'Orbigny), BLOW, 1969, Proc. First International Conference on Planktonic Microfossils, vol. 1, p. 325.

Globigerinoides quadrilobatus sacculifer (Brady). Pl. 3, fig. 5-6

Globigerina sacculifera BRADY, 1877, Geol. Mag., (new ser.) Decade 2, vol. 4, no. 12, p. 535.

Globigerinoides quadrilobatus sacculifer (Brady), BLOW, 1969, Proc. First International Conference on Planktonic Microfossils, vol. 1, p. 326.

Globigerinoides ruber (d'Orbigny). Pl. 3, fig. 7

Globigerina rubra D'ORBIGNY, 1839, Foraminifères, *in* DE LA SAGRA, Hist. Phys., Pol., Nat. Cuba, p. 82, pl. 4, fig. 12-14.

Globigerinoides ruber (d'Orbigny), CORDEY, 1967, Paleontology, vol. 10, pt. 4, p. 647-659, pl. 103, fig. 7-14; text-fig. 1a-d, text-fig. 3 (fig. 3a-5b).

Globorotalia (Turborotalia) scitula scitula (Brady)

Pulvinulina scitula BRADY, 1882, Roy. Soc. Edinburgh, Proc., vol. 11 (1880-1882), no. 111, p. 716-717.

Globorotalia scitula (Brady), CUSHMAN and HENBEST, 1940, U.S. Geol. Surv., Prof. Paper 196-A, pt. 2, p. 36, pl. 8, fig. 5a-c.

Globorotalia scitula scitula (Brady), BLOW, 1959, Bull. Amer. Paleontology, vol. 39, no. 178, p. 219, pl. 19, fig. 126a-c.

Globorotalia (Turborotalia) scitula scitula (Brady), BLOW, 1969, Proc. First International Conference on Planktonic Microfossils, vol. 1, p. 356, pl. 39, fig. 7.

Hastigerina (Hastigerina) siphonifera siphonifera (d'Orbigny). Pl. 5, fig. 4

Globigerina siphonifera D'ORBIGNY, 1839, Foraminifères, *in* DE LA SAGRA, Hist. Phy., Pol., Nat. Cuba, p. 83, pl. 4, fig. 15-18.

Globigerina aequilateralis BRADY, 1879, Quart, Jour. Micr. Science, (new ser.) vol. 19, p. 285.

Globigerina aequilateralis Brady var. *involuta* CUSHMAN, 1917, U.S. Natl. Mus., Proc., vol. 51, no. 2172, p. 662.

Hastigerina (Hastigerina) siphonifera (d'Orbigny), BANNER and BLOW, 1960, Micropaleontology, vol. 6, no. 1, p. 22, text-fig. 2, 3.

Globigerinella siphonifera (d'Orbigny) PARKER, 1967, Bull. Amer. Paleontology, vol. 52, no. 235, p. 152-153, pl. 22, fig. 5.

Hastigerina (Hastigerina) siphonifera siphonifera (d'Orbigny), BLOW, 1969, Proc. First International Conference on Planktonic Microfossils, vol. 1, p. 375.

Sphaeroidinellopsis subdehiscens subdehiscens (Blow). Pl. 5, fig. 9

Sphaeroidinella dehiscens subdehiscens BLOW, 1959, Bull. Amer. Paleontology, vol. 39, no. 178, p. 195, pl. 12, fig. 71, 72.

Sphaeroidinellopsis subdehiscens subdehiscens (Blow), BLOW, 1969, Proc. First International Conference on Planktonic Microfossils, vol. 1, p. 338, pl. 30, fig. 1-3; pl. 31, fig. 1-3; pl. 32, fig. 1-3.

Orbulina universa d'Orbigny. Pl. 5, fig. 5

Orbulina universa D'ORBIGNY, 1839, Foraminifères, *in* DE LA SAGRA, Hist. Phys., Pol., Nat. Cuba, p. 2, pl. 1, fig. 1.

Globigerinita uvula (Ehrenberg). Pl. 2, fig. 9

Pylodexia uvula EHRENBERG, 1861, K. Preuss. Akad. Wiss. Berlin, Monatsber., p. 276, 277, 308.

Globigerina sp. BRADY, 1884, Rept. Voy.

Challenger, Zoology, vol. 9, p. 603, pl. 82, fig. 8, 9.
Globigerina bradyi WIESNER *in* DRYGALSKI, 1931, Deutsche Südpolar Exped. 1901-1903, vol. 20, (Zoology, vol. 12), p. 133.
Globigerinoides minuta NATLAND, 1938, Univ. Calif., Scripps Inst. Oceanography, Bull., Tech. Ser., vol. 4, no. 5, p. 150, pl. 7, fig. 2, 3.
Globigerinia uvula (Ehrenberg), PARKER, 1962, Micropaleontology, vol. 8, no. 2, p. 252, pl. 8, fig. 14-26.

Globoquadrina venezuelana (Hedberg). Pl. 4, fig. 1
Globigerina venezuelana HEDBERG, 1937, Jour. Paleontology, vol. 11, p. 681, pl. 92, fig. 7.
Globoquadrina venezuelana (Hedberg), BLOW, 1959, Bull. Amer. Paleontology, vol. 39, p. 186, pl. 11, fig. 58-59.

B. CALCAREOUS NANNOFOSSILS

Sphenolithus abies Deflandre. Pl. 8, fig. 18-19.
Sphenolithus abies DEFLANDRE, 1954, *in* DEFLANDRE and FERT, Ann. Paléontologie, vol. 40, p. 164, pl. 10, fig. 1-4.
Sphenaster metula WILCOXON, 1970, Tulane Stud. Geol. Paleont., vol. 8, no. 2, p. 80, pl. 1, fig. 1-8; pl. 2, fig. 1-6.

Remarks: Wilcoxon's illustrations are views of the basal apparatus of *Sphenolithus abies* Deflandre.

Emiliania annula (Cohen). Pl. 7, fig. 14-15
Coccolithites annulus COHEN, 1964, Micropaleontology, vol. 10, p. 237, pl. 3, fig. 1a-e.
Cyclolithella annulus (Cohen), McINTYRE and BÉ, 1967, Deep-Sea Research, vol. 14, p. 568, pl. 5, fig. A-C.
Emiliania annula (Cohen), BUKRY, 1971, Initial Reports Deep Sea Drilling Project, fol. 8, p. 1514.

Discoaster asymmetricus Gartner. Pl. 7, fig. 17
Discoaster asymmetricus GARTNER, 1969, Gulf Coast Assoc. Geol. Soc., Trans., vol. 19, p. 598, pl. 1, fig. 1-3.

Discoaster brouweri Tan Sin Hok. Pl. 7, fig. 16, 20-22
Discoaster brouweri TAN SIN HOK, 1927, Jaarb. Mijnw. Nederl.-Indie, vol. 55, p. 120, text-fig. 2, 8a, b.

Gephyrocapsa caribbeanica Boudreaux and Hay. Pl. 8, fig. 5
Gephyrocapsa caribbeanica BOUDREAUX and HAY, 1967, *in* HAY *et al.*, Gulf Coast Assoc. Geol. Soc., Trans., vol. 17, p. 447, pl. 12, fig. 1-4; pl. 13, fig. 1-4.

Ceratolithus cristatus Kamptner. Pl. 6, fig. 1
Ceratolithus cristatus KAMPTNER, 1954, Archiv. Protistenk., vol. 100, p. 43, text-fig. 44-55.

Coccolithus doronicoides Black and Barnes. Pl. 6, fig. 4-7
Coccolithus doronicoides BLACK and BARNES, 1961, Roy. Micros. Soc., Jour., (ser. 3) vol. 80, pt. 2, p. 142, pl. 25, fig. 3.
Ellipsoplacolithus galenis KAMPTNER, 1967, Naturh. Mus. Wien, Ann., vol. 71, p. 140, pl. 6, fig. 41.

Remarks: In pre-Pliocene formations and even in rocks of middle and lower Pliocene age, specimens referred to this species may be pseudomorphs. Fragmentation or solution of the bridge in the central area of species of *Gephyrocapsa*, for example, can pose problems in speciation. Validity of biostratigraphic use of the taxon remains to be established.

Discoaster exilis Martini and Bramlette. Pl. 7, fig. 18
Discoaster exilis MARTINI and BRAMLETTE, 1963, Jour. Paleontology, vol. 37, p. 852, pl. 104, fig. 1-3.

Helicopontosphaera kamptneri Hay and Mohler. Pl. 8, fig. 9
Coccolithus carteri (Wallich), KAMPTNER, 1941, Naturh. Mus. Wien, Ann., vol. 51, p. 93, 111, pl. 13, fig. 136 (not *Coccosphaera carteri* Wallich, 1877, Ann. Mag. Nat. Hist., ser. 4, vol. 19, p. 348, pl. 17, fig. 3, 4, 6, 7, 17).
Helicosphaera carteri (Wallich), KAMPTNER, 1954, Archiv. Protistenk., vol. 100, no. 1, p. 21, text-fig. 17-19.
Helicopontosphaera kamptneri HAY and MOHLER, 1967, *in* HAY *et al.*, Gulf Coast Assoc. Geol. Soc., Trans., vol. 17, p. 448, pl. 10, 11, fig. 5.

Pseudoemiliania lacunosa (Kamptner). Pl. 8, fig. 11, 17
Ellipsoplacolithus exsectus KAMPTNER, 1963, Naturh. Mus. Wien, Ann., vol. 66, p. 171, pl. 9, fig. 51, 52 (fig. 52 is incorrectly labelled).
Ellipsoplacolithus lacunosus KAMPTNER, 1963, Naturh. Mus. Wien, Ann., vol. 66, p. 172, pl. 9, fig. 50.
Coccolithus doronicoides Black *partim*, McINTYRE, BÉ, and PREIKSTAS, 1967, Progress in Oceanography, vol. 4, p. 8, pl. 3, fig. A.
Umbilicosphaera cricota (Gartner), COHEN and REINHARDT, 1968, Nueves Jahrb. Geologie Paläontologie Abh., vol. 131, p. 296, pl. 21, fig. 3.
Pseudoemiliania lacunosa (Kamptner), GART-

NER, 1969, Gulf Coast Assoc. Geol. Soc., Trans., vol. 19, p. 598, pl. 2, fig. 9, 10.

Cyclococcolithina leptopora (Murray and Blackman). Pl. 7, fig. 9-13
Coccosphaera leptopora MURRAY and BLACKMAN, 1898, Roy. Soc. London, Phil. Trans., (ser. B) vol. 190, p. 430, pl. 15, fig. 1-7.
Coccolithophora leptopora (Murray and Blackman), LOHMANN, 1902, Archiv. Protistenk., vol. 1, p. 138, pl. 5, fig. 52, 61-64.
Coccolithus leptoporus (Murray and Blackman), SCHILLER, 1930, *in* L. RABENHORST, Kryptogamen-Flora, vol. 10, p. 245, text-fig. 10.
Cyclococcolithus leptoporus (Murray and Blackman), KAMPTNER, 1954, Archiv. Protistenk., vol. 100, p. 23, fig. 20.
Cyclococcolithina leptopora (Murray and Blackman), WILCOXON, 1970, Tulane Stud. Geol. Paleont., vol. 8, no. 2, p. 82.

Cyclococcolithina macintyrei (Bukry and Bramlette). Pl. 7, fig. 6-8
Coccolithus leptoporus (Murray and Blackman), McINTYRE, BÉ, and PREIKSTAS, 1967, Progress in Oceanography, vol. 4, p. 9 *(partim)*, pl. 2, fig. A, B (not pl. 4, fig. C, D; pl. 5, fig. A, C, D).
Cyclococcolithus macintyrei BUKRY and BRAMLETTE, 1969, Tulane Stud. Geol. Paleont., vol. 7, no. 3, p. 132, pl. 1, fig. 1-3.
Cyclococcolithina macintyrei (Bukry and Bramlette), GARTNER, 1973, Geol. Soc. America, Bull., vol. 84, no. 6, p. 2021.

Cristallolithus macroporus (Deflandre). Pl. 7, fig. 4
Discolithus macroporus DEFLANDRE, 1954, *in* DEFLANDRE and FERT, Ann. Paléontologie, vol. 40, p. 24, pl. 11, fig. 5.
Discolithina macroporus (Deflandre), LEVIN and JOERGER, 1967, Micropaleontology, vol. 13, p. 167, pl. 2, fig. 5.
Cristallolithus macroporus (Deflandre), SACHS and SKINNER, 1973, Tulane Stud. Geol. Paleont., vol. 10, no. 3, p. 154-155, pl. 5, fig. 1-4.

Umbilicosphaera mirabilis Lohmann. Pl. 8, fig. 20
Umbilicosphaera mirabilis LOHMANN, 1902, Archiv. Protistenk., vol. 1, p. 139, pl. 5, fig. 66, 66a.
Cyclococcolithus mirabilis (Lohmann), KAMPTNER, 1954, Archiv. Protistenk., vol. 100, p. 24, text-fig. 21-23.

Cristallolithus multiporus (Kamptner), new combination. Pl. 7, fig. 5
Discolithus multiporus Kamptner, 1948, Sitz Ber. Österr. Akad. Wiss., Math.-Naturw. Kl., vol. 157, pt. 1, p. 5, pl. 1, fig. 9.
Discolithina multipora (Kamptner), MARTINI, 1965, Proc. 17th Symp. Colston. Res. Soc., London, p. 400.

Coccolithus pelagicus (Wallich). Pl. 7, fig. 1-3
Coccosphaera pelagica WALLICH, 1877, Ann. Mag. Nat. Hist., (ser. 4) vol. 19, p. 348, pl. 17, fig. 1, 2, 5, 11, 12.
Coccolithus pelagicus (Wallich) SCHILLER, 1930, *in* L. RABENHORST, Kryptogamen-Flora, Leipzig, vol. 10, p. 246.

Discoaster pentaradiatus Tan Sin Hok. Pl. 7, fig. 19
Discoaster pentaradiatus TAN SIN HOK, 1927, Jaarb. Mijnw. Nederl.-Indie, vol. 55, p. 120, fig. 2.

Lithostromation perdurum Deflandre. Pl. 8, fig. 10
Lithostromation perdurum DEFLANDRE, 1942, Acad. Sci. (Paris), C. R., vol. 214, p. 919, fig. 1-9.

Discoaster perplexus Bramlette and Riedel. Pl. 7, fig. 23-24
Discoaster perplexus BRAMLETTE and RIEDEL, 1954, Jour. Paleontology, vol. 28, p. 400, pl. 39, fig. 9.

PLATE 1

Figures
1. *Candeina nitida nitida* d'Orbigny
   Concepcion Inferior Formation, TU 1025
   a. Spiral view, ×188
   b. Side view, ×188
2. *Globigerina nepenthes* Todd
   Concepcion Superior Formation, TU 1026
   Umbilical view, ×234
3. *Globigerina juvenilis* Bolli
   Agueguexquite Formation, TU 638
   a. Umbilical view, ×283
   b. Spiral view, ×283

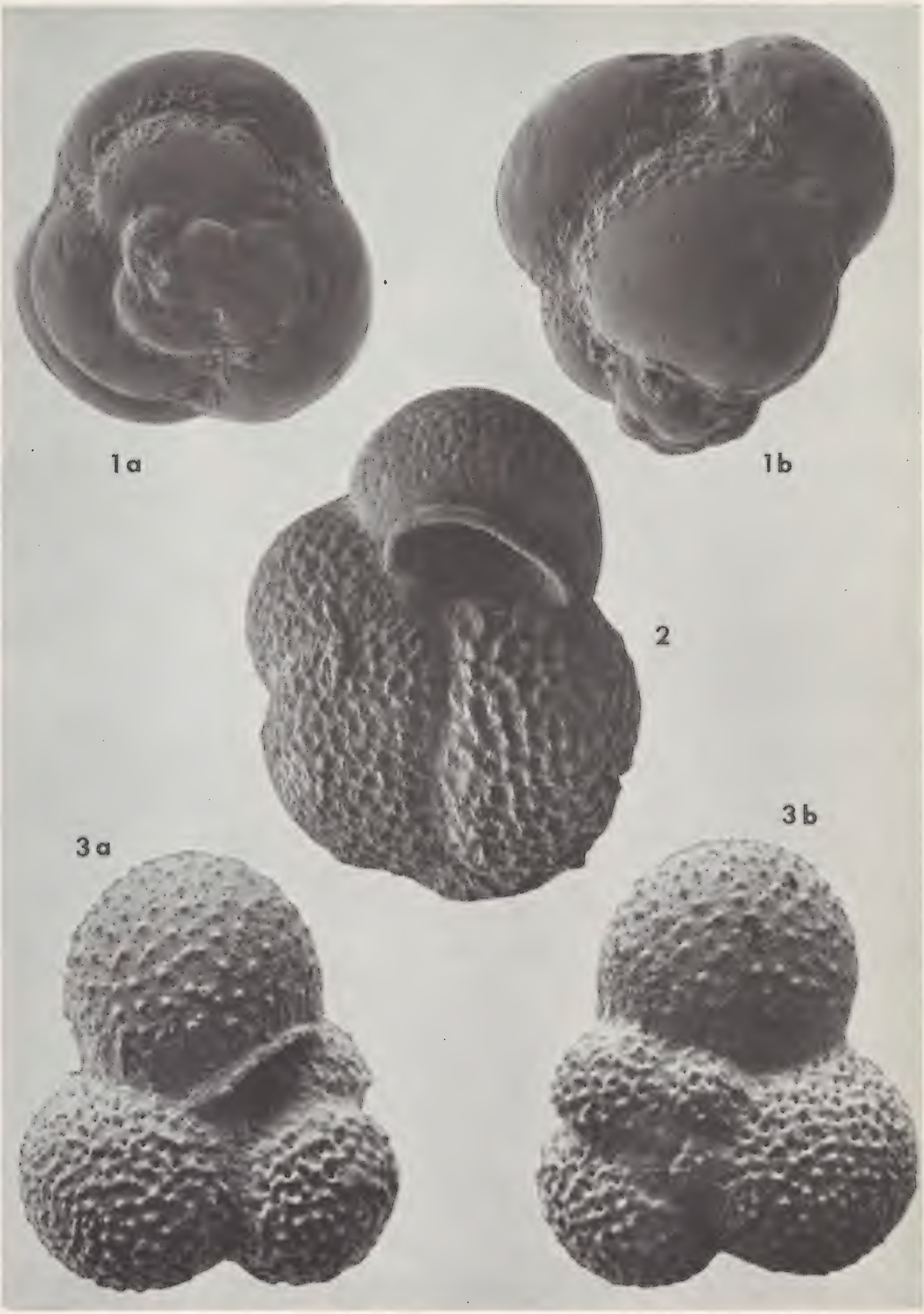

PLATE 1

Reticulofenestra pseudoumbilica (Gartner). Pl. 8, fig. 12-16
Coccolithus pseudoumbilicus GARTNER, 1967, Kans. Univ. Paleontological Contr., Paper 29, p. 4, pl. 6, fig. 1-4.
Reticulofenestra pseudoumbilica (Gartner), GARTNER, 1969, Gulf Coast Assoc. Geol. Soc., Trans., vol. 19, p. 598, pl. 2, fig. 4.

Gephyrocapsa reticulata Nishida. Pl. 8, fig. 6-7
Gephyrocapsa reticulata NISHIDA, 1971, Palaeontological Soc. Japan, Trans. Proc., (new ser.) vol. 83, p. 150, pl. 17, fig. 1-3.

Ceratolithus rugosus Bukry and Bramlette. Pl. 6, fig. 2-3
Ceratolithus rugosus BUKRY and BRAMLETTE, 1968, Tulane Stud. Geol. Paleont., vol. 6, no. 4, pl. 152, pl. 1, fig. 5-9.

Discoaster surculus Martini and Bramlette. Pl. 8, fig. 1-2
Discoaster surculus MARTINI and BRAMLETTE, 1963, Jour. Paleontology, vol. 37, p. 854, pl. 104, fig. 10-12.

Discoaster variabilis Martini and Bramlette. Pl. 8, fig. 3-4
Discoaster variabilis MARTINI and BRAMLETTE, 1963, Jour. Paleontology, vol. 37, p. 854, pl. 104, fig. 4-9.

VI. SUPPLEMENTARY LOCALITY DATA

The following are Tulane University fossil locality numbers:

638. Agueguexquite Formation.
Roadcut, pipeline cut, and quarry on both

PLATE 2

Figures
1. *Biorbulina bilobata* (d'Orbigny)
Concepcion Superior Formation, TU 1026
×99
2. *Globigerina bulloides apertura* Cushman
Agueguexquite Formation, TU 638
   a. Apertural view, ×127
   b. Spiral view, ×127
3. *Globigerina bulloides apertura* Cushman
Filisola Formation, TU 1141
Apertural view, ×104
4. *Globigerina bulloides bulloides* d'Orbigny
Concepcion Superior Formation, TU 1026
Spiral view, ×115
5. *Globigerina bulloides bulloides* d'Orbigny
Concepcion Inferior Formation, TU 1025
Umbilical view, ×91
6. *Globigerina bulloides bulloides* d'Orbigny
Agueguexquite Formation, TU 638
   a. Spiral view, ×110
   b. Umbilical view, ×117
7. *Globigerina calida praecalida* Blow
Unnamed formation, TU 1136
Umbilical view, ×121
8. *Globigerina decoraperta* Takayanagi and Saito
Unnamed formation, TU 1136
Umbilical view, ×134
9. *Globigerinita uvula* (Ehrenberg)
Concepcion Inferior Formation, TU 1025
   a. Umbilical view, ×250
   b. Spiral view, ×250
10. *Globigerinoides conglobatus conglobatus* (Brady)
Concepcion Inferior Formation, TU 1025
   a. Spiral view, ×96
   b. Umbilical view, ×96

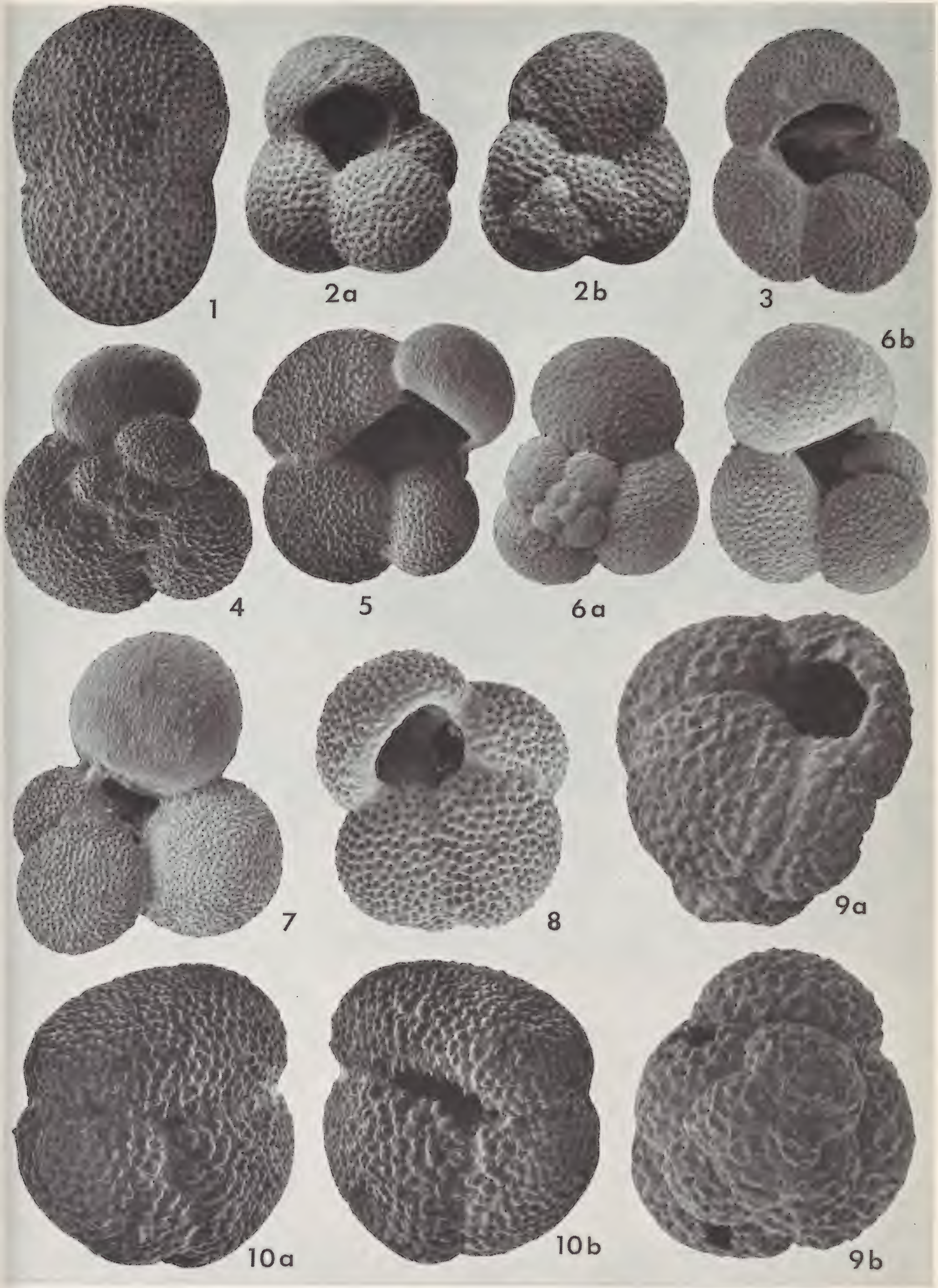

PLATE 2

sides of Mexico Highway 180, 14 miles east of the junction with the side road to Coatzacoalcos, Veracruz. Sampled May, 1972, by H. E. and E. H. Vokes and W. H. Akers. Material for this report was taken from the pipe line cut, north of the highway. Nineteen samples were collected at one-meter intervals from the base to the top of the exposure by Ronald Parsley and W. H. Akers. The latter outcrop subsequently has been removed by additional construction, but a representative sample sequence is deposited in the Tulane University Department of Earth Sciences.

1025. Concepcion Inferior Formation.
Roadcut on east side of road from Nuevo Teapa to Ixhuatlan, 0.5 mile south of junction with Mexico Highway 180, State of Veracruz, Mexico. Stop no. 5 of the 20th International Geological Congress, Excursion C-7 (see Contreras Velazquez *et al.*, 1956, p. 176; Vokes, 1970, p. 49). Collected by W. H. Akers, with H. E. and E. H. Vokes, May, 1972.

1026. Concepcion Superior Formation.
Road metal quarry (State of Veracruz) on Mexico Highway 175, about one mile north of the bridge over the Tonto River (just above confluence with the Papaloapan River), near Tuxtepec, Oaxaca, Mexico. See Contreras Velazquez (1956, p. 56-58). Collected by W. H. Akers with H. E. and E. H. Vokes, May, 1972.

1046. Agueguexquite Formation.
Roadcuts, both sides of Mexico Highway 180, 7½ miles east of the junction with side road into Coatzacoalcos, Veracruz; within ½ mile of the type locality. See Perrilliat Montoya (1963). Sample collected by W. H. Akers with H. E. and E. H. Vokes, May, 1972.

1083. Unnamed formation.
Roadcut on Mexico Highway 185, 3.0 miles north of Sayula, Veracruz, Mexico. Collected

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PLATE 3

Figures

1. *Globigerinoides obliquus extremus* Bolli and Bermúdez
Concepcion Inferior Formation, TU 1025
   a. Spiral view, ×103
   b. Umbilical view, ×103
2. *Globigerinoides obliquus obliquus* Bolli
Concepcion Inferior Formation, TU 1025
Umbilical view, ×103
3. *Globigerinoides obliquus obliquus* Bolli
Concepcion Superior Formation, TU 1026
Spiral view, ×94
4. *Globigerinoides quadrilobatus quadrilobatus* (d'Orbigny)
Concepcion Superior Formation, TU 1026
   a. Spiral view, ×95
   b. Umbilical view, ×95
5. *Globigerinoides quadrilobatus sacculifer* (Brady)
Concepcion Inferior Formation, TU 1025
Spiral view, ×64
6. *Globigerinoides quadrilobatus sacculifer* (Brady)
Unnamed formation, TU 1083
Umbilical view, ×69
7. *Globigerinoides ruber* (d'Orbigny)
Concepcion Inferior Formation, TU 1025
   a. Umbilical view, ×94
   b. Spiral view, ×94
8. *Globoquadrina altispira altispira* (Cushman and Jarvis)
Concepcion Inferior Formation, TU 1025
Side view, ×107
9. *Globoquadrina conglomerata* (Schwager)
Concepcion Inferior Formation, TU 1025
   a. Spiral view, ×94
   b. Umbilical view, ×94
10. *Globoquadrina altispira globosa* Bolli
Unnamed formation, TU 1083
Umbilical view, ×70

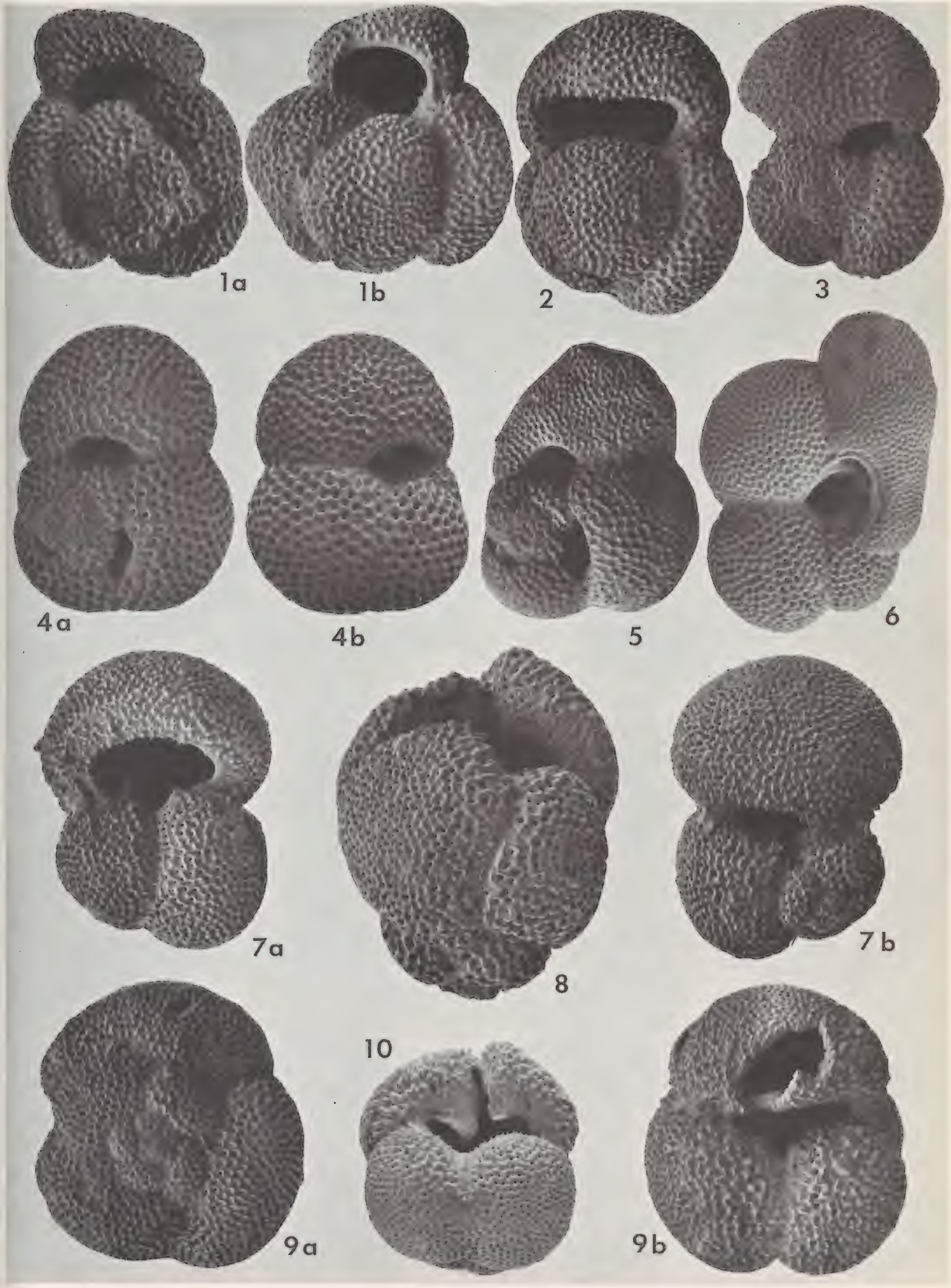

PLATE 3

by W. H. Akers with H. E. and E. H. Vokes, May, 1972.

1136. Unnamed formation.
Roadcut at K 15 on Mexico Highway 185, south of Acayucan, Veracruz, Mexico. Collected by W. H. Akers with H. E. and E. H. Vokes, May, 1972.

1141. Filisola Formation.
Roadcut on the north side of Mexico Highway 180, 13 kilometers west of San Andreas Tuxtla, Veracruz. Stop no. 10 of the 20th International Geological Congress, Excursion C-7 (see Viniegra *et al.*, 1956, p. 163). Collected by W. H. Akers with H. E. and E. H. Vokes, May, 1972.

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PLATE 4

Figures

1. *Globoquadrina venezuelana* (Hedberg)
Concepcion Inferior Formation, TU 1025
   a. Spiral view, ×113
   b. Umbilical view, ×113
2. *Globorotalia (Globorotalia) crassula conomiozea* Kennett
Concepcion Inferior Formation, TU 1025
   a. spiral view, ×97
   b. Umbilical view, ×97
3. *Globorotalia (Globorotalia) cultrata limbata* (Fornasini)
Agueguexquite Formation, TU 638
   a. Spiral view, ×125
   b. Umbilical view, ×125
4. *Globorotalia (Globorotalia) cultrata menardii* (Parker, Jones and Brady)
Unnamed formation, TU 1136
Umbilical view, ×121
5. *Globorotalia (Globorotalia) cultrata menardii* (Parker, Jones and Brady)
Unnamed formation, TU 1136
Edge view, ×105
6. *Globorotalia (Globorotalia) margaritae* Bolli and Bermúdez
Unnamed formation, TU 1083
Umbilical view, ×108
7. *Globorotalia (Globorotalia) margaritae* Bolli and Bermúdez
Unnamed formation, TU 1083
Spiral view, ×109
8. *Globorotalia (Globorotalia) margaritae* Bolli and Bermúdez
Unnamed formation, TU 1083
Edge view, ×108
9. *Globorotalia (Globorotalia) cultrata menardii* (Parker, Jones and Brady)
Unnamed formation, TU 1083
Spiral view, ×58
10. *Globorotalia (Globorotalia)* cf. *Globorotalia multicamerata* Cushman and Jarvis
Concepcion Superior Formation, TU 1026
   a. Spiral view, ×57
   b. Umbilical view, ×57
11. *Globorotalia (Turborotalia) acostaensis acostaensis* Blow
Agueguexquite Formation, TU 638
   a. Spiral view, ×118
   b. Umbilical view, ×118

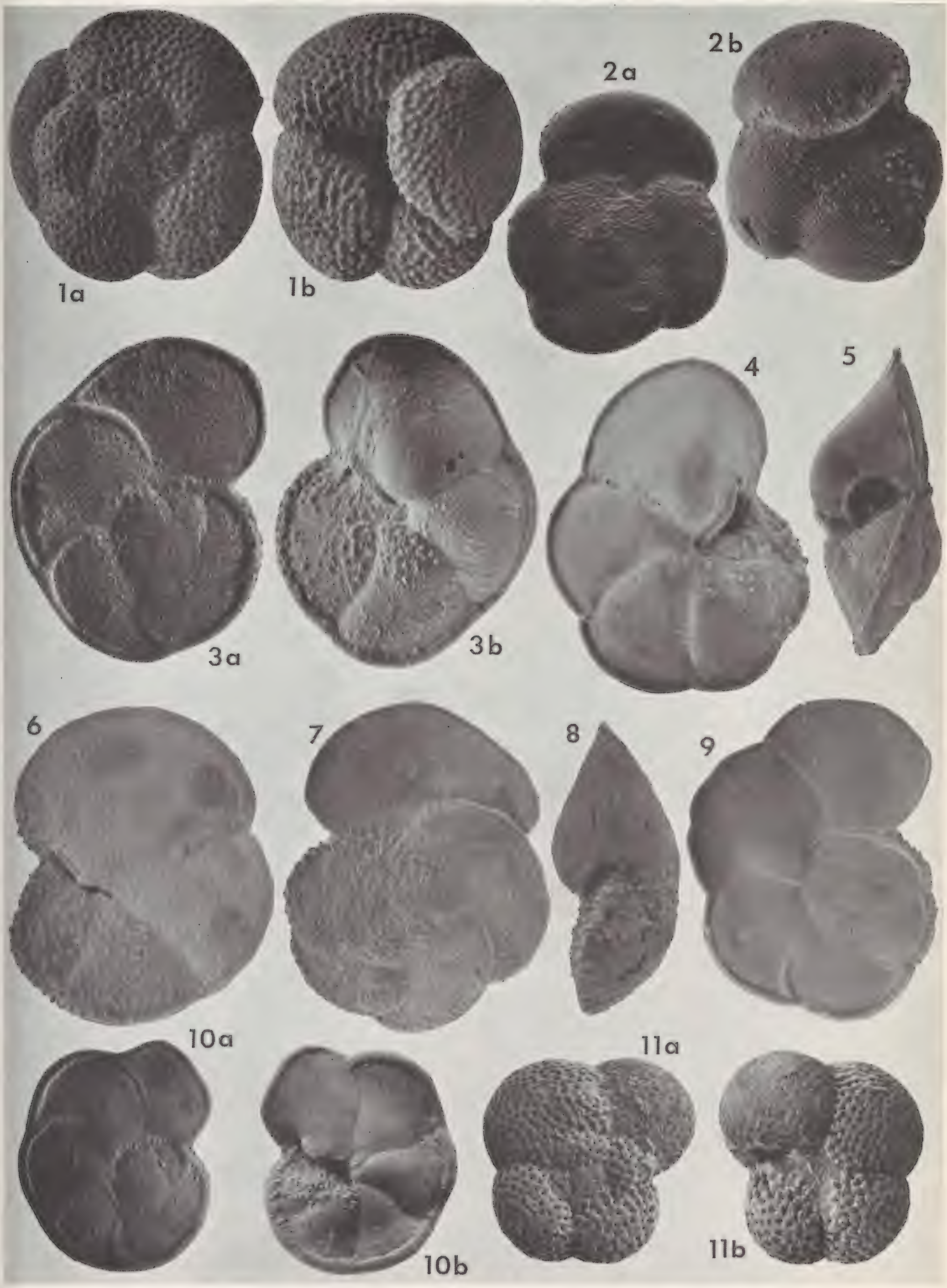

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PLATE 5

Figures

1. *Globorotalia (Turborotalia) acostaensis humerosa* Takayanagi and Saito
   Concepcion Inferior Formation, TU 1025
   a. Spiral view, ×98
   b. Umbilical view, ×98
2. *Globorotalia (Turborotalia) crassacrotonensis* Conato and Follador
   Unnamed formation, TU 1083
   a. Edge view, ×105
   b. Spiral view, ×106
   c. Umbilical view, ×107
3. *Globorotalia (Turborotalia) acostaensis pseudopima* Blow
   Concepcion Inferior Formation, TU 1025
   a. Umbilical view, ×96
   b. Spiral view, ×96
4. *Hastigerina (Hastigerina) siphonifera siphonifera* (d'Orbigny)
   Agueguexquite Formation, TU 638
   a. Edge view, ×95
   b. Umbilical view, ×95
5. *Orbulina universa* d'Orbigny
   Concepcion Superior Formation, TU 1026
   ×100
6. *Globorotalia (Turborotalia) acostaensis humerosa* Takayanagi and Saito
   Filisola Formation, TU 1141
   Umbilical view, ×104
7. *Sphaeroidinella dehiscens dehiscens forma immatura* (Cushman)
   Agueguexquite Formation, TU 638
   a., b. Opposite views, ×116
8. *Prosphaeroidinella parkerae* Ujiié
   Filisola Formation, TU 1141
   Umbilical view, ×104
9. *Sphaeroidinellopsis subdehiscens subdehiscens* (Blow)
   Concepcion Inferior Formation, TU 1025
   Umbilical view, ×97

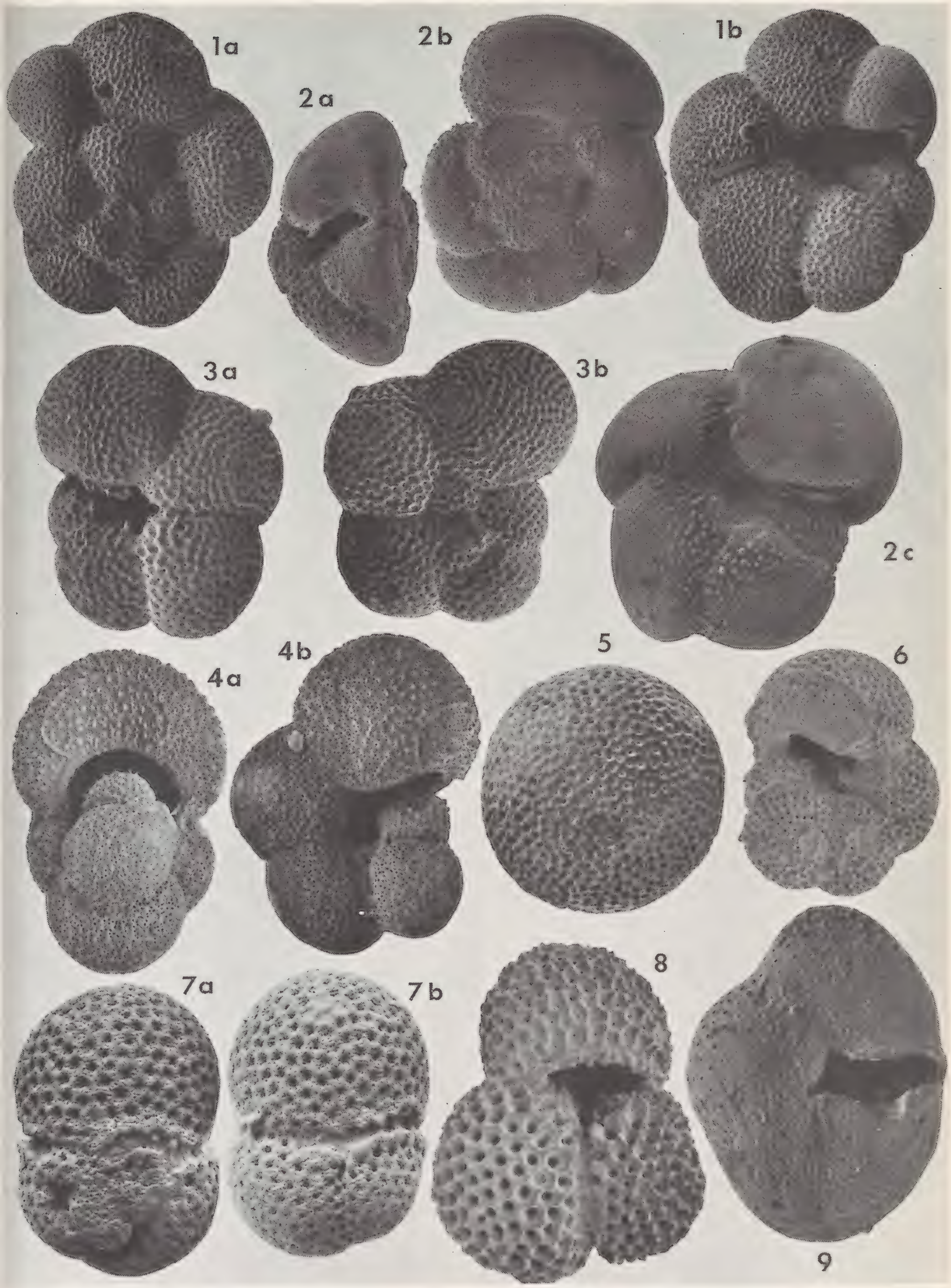

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PLATE 6

Figures

1. *Ceratolithus cristatus* Kamptner, Stereoscan micrograph, ×10,000
   Concepcion Inferior Formation, TU 1025
2. *Ceratolithus rugosus* Bukry and Bramlette, light micrograph, polarized light, ×3150
   Unnamed formation, TU 1083
3. *Ceratolithus rugosus* Bukry and Bramlette, light micrograph, plain light, ×3150
   Unnamed formation, TU 1083
4. *Coccolithus doronicoides* Black and Barnes, light micrograph, polarized light ×3150
   Unnamed formation, TU 1083
5. *Coccolithus doronicoides* Black and Barnes, light micrograph, polarized light, ×3150
   Agueguexquite Formation, TU 638
6. *Coccolithus doronicoides* Black and Barnes, Stereoscan micrograph, ×20,000
   Unnamed formation, TU 1083
7. *Coccolithus doronicoides* Black and Barnes, Stereoscan micrograph, ×10,000
   Agueguexquite Formation, TU 638

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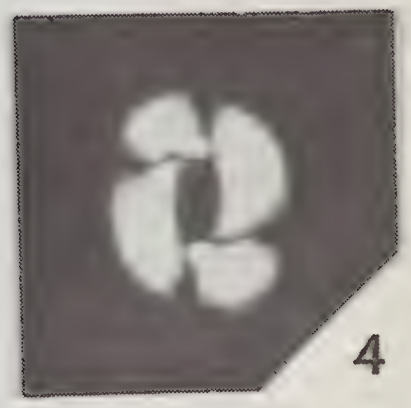
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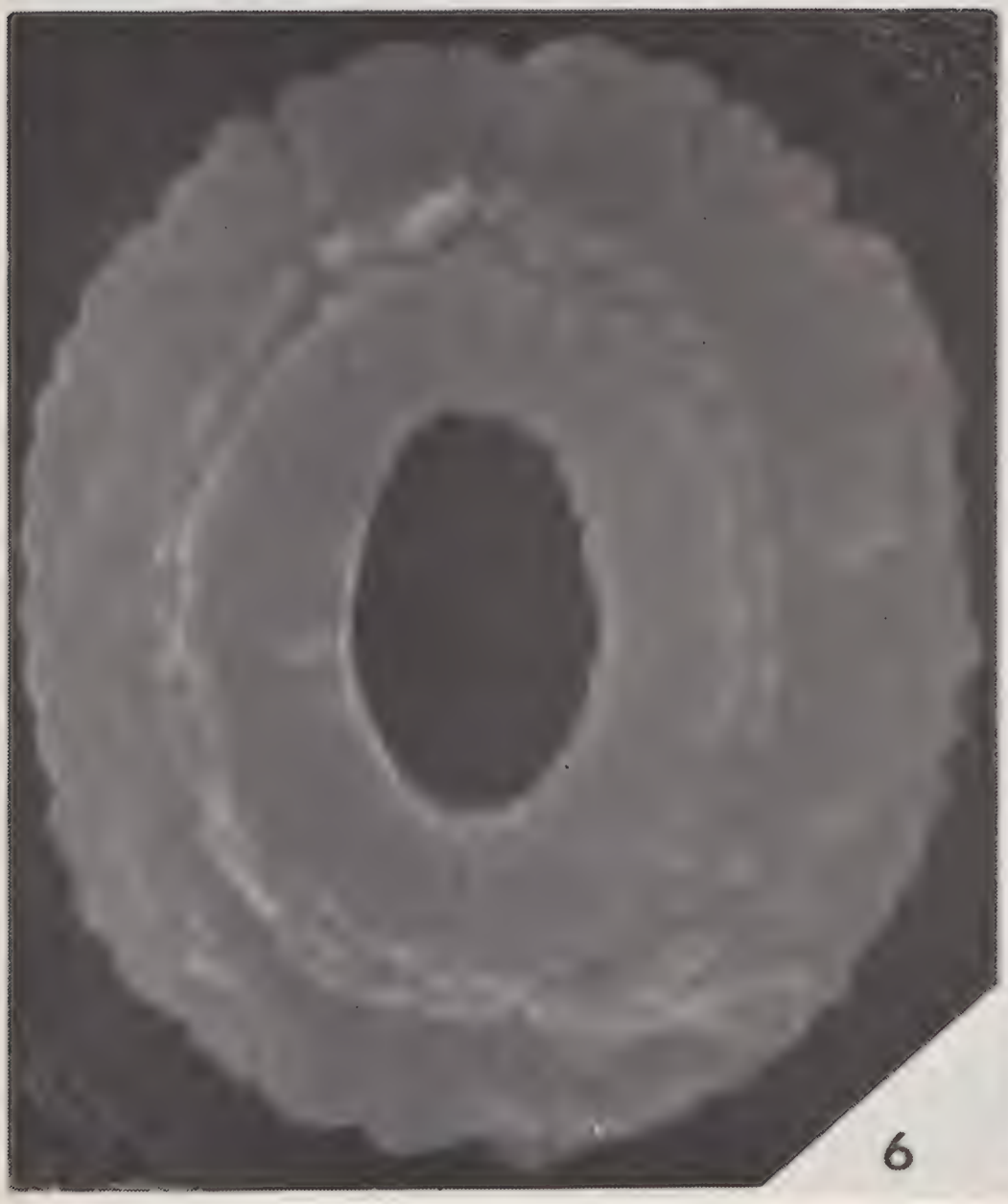
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PLATE 6

PLATE 7

Figures

1. *Coccolithus pelagicus* (Wallich), Stereoscan micrograph, ×5000
   Unnamed formation, TU 1083
2. - 3. *Coccolithus pelagicus* (Wallich), light micrographs, polarized light, ×1575
   Unnamed formation, TU 1083
4. *Cristallolithus macroporus* (Deflandre), Stereoscan micrograph, ×10,000
   Unnamed formation, TU 1136
5. *Cristallolithus multiporus* (Kamptner), Stereoscan micrograph, ×2500
   Unnamed formation, TU 1083
6. *Cyclococcolithina macintyrei* (Bukry and Bramlette), Stereoscan micrograph, ×2500
   Unnamed formation, TU 1083
7. *Cyclococcolithina macintyrei* (Bukry and Bramlette), Stereoscan micrograph, ×2500
   Concepcion Superior Formation, TU 1026
8. *Cyclococcolithina macintyrei* (Bukry and Bramlette), light micrograph, plain light, ×1575
   Unnamed formation, TU 1083
9. *Cyclococcolithina leptopora* (Murray and Blackman), light micrograph, polarized light, ×1575
   Agueguexquite Formation, TU 638
10. *Cyclococcolithina leptopora* (Murray and Blackman), Stereoscan micrograph, ×5000
    Concepcion Superior Formation, TU 1026
11. - 12. *Cyclococcolithina leptopora* (Murray and Blackman), light micrographs, plain light, ×1575
    Unnamed formation, TU 1083
13. *Cyclococcolithina leptopora* (Murray and Blackman), Stereoscan mirograph, ×5000
    Unnamed formation, TU 1083
14. *Emiliania annula* (Cohen), Stereoscan micrograph, ×5000
    Unnamed formation, TU 1083
15. *Emiliania annula* (Cohen), light micrograph, polarized light ×1575
    Unnamed formation, TU 1083
16. *Discoaster brouweri* Tan Sin Hok, Stereoscan micrograph, ×2500
    Concepcion Superior Formation, TU 1026
17. *Discoaster asymmetricus* Gartner, Stereoscan micrograph, ×5000
    Concepcion Inferior Formation, TU 1025
18. *Discoaster exilis* Martini and Bramlette, Stereoscan micrograph, ×2500
    Unnamed formation, TU 1083
19. *Discoaster pentaradiatus* Tan Sin Hok, Stereoscan micrograph, ×2500
    Agueguexquite Formation, TU 638
20. *Discoaster brouweri* Tan Sin Hok, Stereoscan micrograph, ×2500
    Unnamed formation, TU 1136
21. *Discoaster brouweri* Tan Sin Hok, Stereoscan micrograph, ×2500
    Unnamed formation, TU 1083
22. *Discoaster brouweri* Tan Sin Hok, light micrograph, plain light, ×1575
    Unnamed formation, TU 1083
23. *Discoaster perplexus* Bramlette and Riedel, light micrograph, plain light, ×1575
    Unnamed formation, TU 1083
24. *Discoaster perplexus* Bramlette and Riedel, Stereoscan micrograph, ×5000
    Unnamed formation, TU 1136

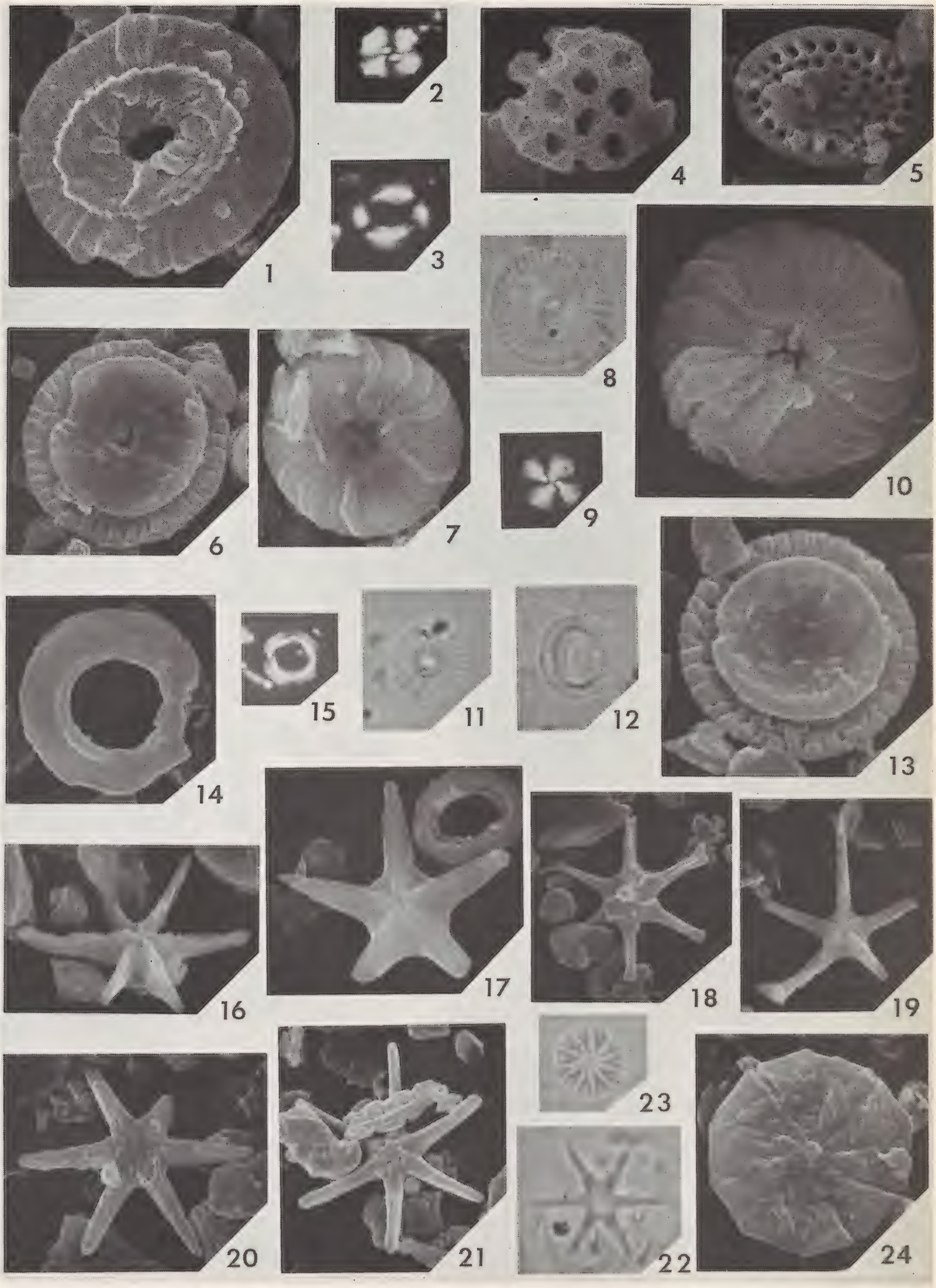

PLATE 7

PLATE 8

Figures

1. *Discoaster surculus* Martini and Bramlette, Stereoscan micrograph, ×2500
   Concepcion Superior Formation, TU 1026
2. *Discoaster surculus* Martini and Bramlette, light micrograph, plain light, ×1575
   Unnamed formation, TU 1083
3. *Discoaster variabilis* Martini and Bramlette, light micrograph, plain light, ×1575
   Unnamed formation, TU 1083
4. *Discoaster variabilis* Martini and Bramlette, Stereoscan micrograph, ×5000
   Unnamed formation, TU 1083

5a. *Gephyrocapsa* cf. *G. caribbeanica* Boudreaux and Hay, Stereoscan micrograph, ×10,000
   Unnamed formation, TU 1083

5b. *Gephyrocapsa caribbeanica* Boudreaux and Hay, light micrograph, polarized light, ×2520
   Unnamed formation, TU 1083

6. *Gephyrocapsa reticulata* Nishida, Stereoscan micrograph, ×10,000
   Unnamed formation, TU 1136
7. *Gephyrocapsa reticulata* Nishida, Stereoscan micrograph, ×5000
   Agueguexquite Formation, TU 638
8. *Pseudoemiliania lacunosa* (Kamptner), Stereoscan micrograph, ×5000
   Agueguexquite Formation, TU 638
9. *Helicopontosphaera kamptneri* Hay and Mohler, Stereoscan micrograph, ×5000
   Agueguexquite Formation, TU 638
10. *Lithostromation perdurum* Deflandre, Stereoscan micrograph, ×2500
    Unnamed formation, TU 1136

11., 17. *Pseudoemiliania lacunosa* (Kamptner), Stereoscan micrograph, ×10,000
   Unnamed formation, TU 1136

12., 16. *Reticulofenestra pseudoumbilica* (Gartner), Stereoscan micrograph, ×2500
   Concepcion Inferior Formation, TU 1025

13. *Reticulofenestra pseudoumbilica* (Gartner), light micrograph, polarized light, ×1575
   Concepcion Superior Formation, TU 1026
14. *Reticulofenestra pseudoumbilica* (Gartner), Stereoscan micrograph, ×5000
   Concepcion Superior Formation, TU 1026
15. *Reticulofenestra pseudoumbilica* (Gartner), light micrograph, plain light, ×1575
   Concepcion Superior Formation, TU 1026
18. *Sphenolithus abies* Deflandre, Stereoscan micrograph, ×5000
   Unnamed formation, TU 1083
19. *Sphenolithus abies* Deflandre, Stereoscan micrograph, ×5000
   Concepcion Inferior Formation, TU 1025
20. *Umbilicosphaera mirabilis* Lohmann, Stereoscan micrograph, ×5000
   Unnamed formation, TU 1083

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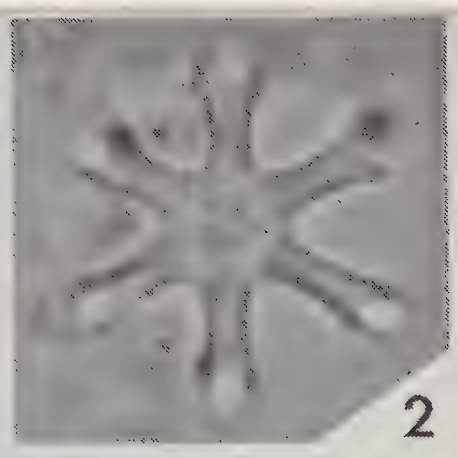
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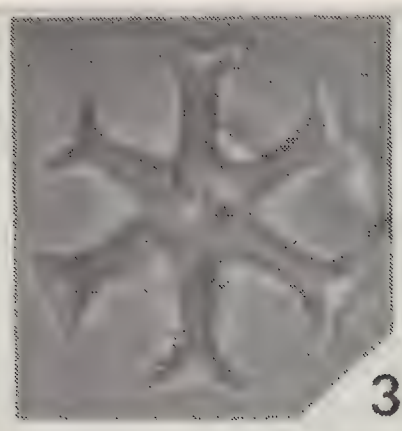
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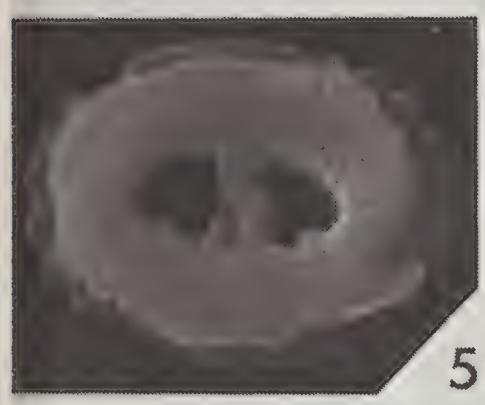
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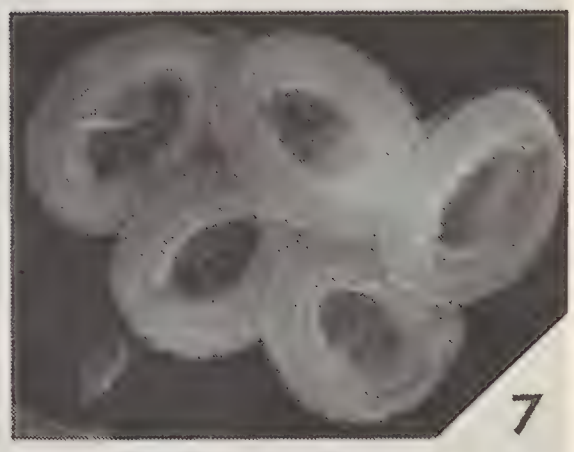
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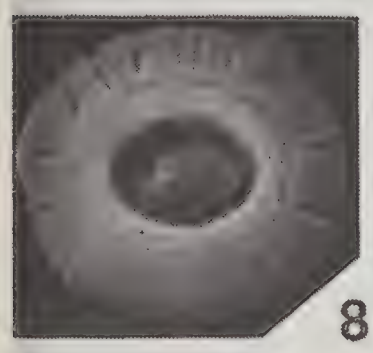
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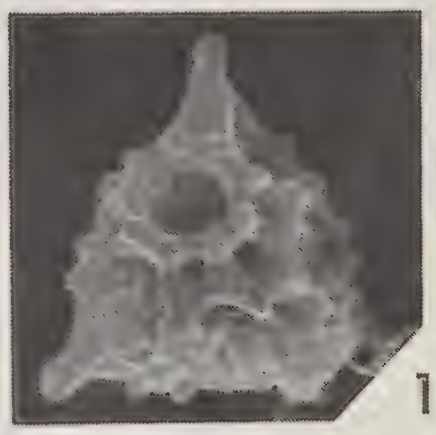
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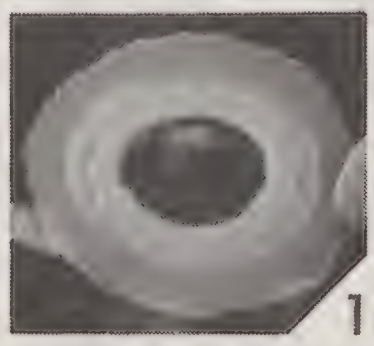
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PLATE 8

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REVIEW

INTRODUCTION TO MARINE MICROPALEONTOLOGY, edited by Bilal U. Haq and Anne Boersma. Published by Elsevier North-Holland, Inc., New York and Oxford, 1978, viii + 376 pp., illustrated, ...$24.00

This volume will be agreeably received by those involved in the study of marine micro-organisms, expecially those confronted with the formidable task of teaching a course on this subject to beginning students. There is no other comprehensive book on marine microfossils available.

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Obviously, it is impossible to treat each of the fourteen in depth and to contain the work in a single volume. However, the authors have done an excellent job of introducing each subject and the book provides an adequate base on which to build for classroom study or research purposes. It is highly recommended for both geologists and paleontologists who need a survey of microfossil morphology. classification, and paleoecology.

—H.C.S.

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OBSERVATIONS ON THE GENUS *DIMYA* (MOLLUSCA:BIVALVIA) IN THE CENOZOIC FAUNAS OF THE WESTERN ATLANTIC REGION

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I. ABSTRACT

The bivalved molluscan genus *Dimya*, heretofore known to be represented in the western Atlantic faunas by one Miocene species and variety from the Dominican Republic (*D. grandis* and var. *divaricata*, both of Dall, 1896) and two Recent species from the Caribbean Sea and adjacent areas (*D. argentea* Dall, 1886, and *D. tigrina* Bayer, 1971), proves to be more widely distributed in the paleontological record. Three new species are described: *D. alleni*, from the Cook Mountain Formation, middle Eocene of Louisiana; *D. rufaripa*, from the lower Oligocene Red Bluff Formation of Mississippi; and *D. fimbricostata*, from the lower Pleistocene Moín Formation of Costa Rica. In addition, other specimens from the Moín Formation are referred to *D. tigrina* Bayer, and, three valves from the well-known Bowden, Jamaica, locality serve to document the occurrence of the genus in that fauna.

The geologic and the geographic distribution of the known fossil and Recent species of *Dimya* and *Dimyodon* is discussed. It is concluded that *Dimya* probably is descended from the Upper Triassic to middle Oligocene genus *Dimyodon*, possibly first appearing in the late Cretaceous, but certainly present in the Paleocene and achieving widespread distribution in the middle and upper Eocene of the Old World Tethyan faunas before becoming relatively rare and apparently confined to the deeper water facies of Oligocene and later faunas. The Pleistocene forms here described constitute the first known records of its occurrence in deposits of that epoch. A number of Recent species are known from the western Atlantic and the Pacific faunas; the average depth for the 47 available dredging records for these species is 311 meters, the few available bottom temperature records average slightly over 59°F (15°C).

Annotated lists of those species that have been referred, at one time or another, to *Dimya* and *Dimyodon* are appended.

II. INTRODUCTION

In 1969, James A. Allen of Alexandria, Louisiana, sent the writer several specimens of a small bivalve species that proved to be referrable to the genus *Dimya* Rouault, 1850. These had been collected from deposits of the Cook Mountain Formation of middle Eocene (Claibornian) age at Columbus, Louisiana, shortly before that area was flooded by the waters impounded behind the Toledo Bend Dam on the Sabine River. A survey of the literature on the genus revealed only one described western Atlantic fossil species and variety (*D.*

grandis Dall and var. *divaricata* Dall, 1896*, "Oligocene *[sic]*, Santo Domingo") and one Recent species, *D. argentea* Dall, 1886. Subsequently, in 1970, Moore described a new genus *Dimyella,* with its minute type species *D. starcki* found attached to the roof of a salt-water cave or tunnel on the island of Cozumel, Quintana Roo, Mexico. In 1971 Bayer added a second Recent species of *Dimya, D. tigrina,* from off Punta Piedras, Colombia, and also described a new genus *Basiliomya,* with type species *B. goreaui* from Discovery Bay, Jamaica, and off Andros Island in the Bahamas. Thus, as of this writing, there are in the western Atlantic Recent faunas four species, two referable to *Dimya* and two to other, presently monotypic, genera, with still but the one fossil species and its variety.

Examination of the paleontological collections at Tulane University disclosed, in addition to the specimens submitted by Mr. Allen and herein named *Dimya alleni,* n. sp., more than 500 valves of *D. grandis* Dall and its variety *divaricata* Dall from the upper Miocene of the Dominican Republic, three specimens of an undetermined species from the famous Bowden, Jamaica, locality (TU 705) and more than 400 specimens of a new, relatively large shelled species, *D. fimbricostata,* from the Moín Formation, Pleistocene of Costa Rica, from whence we also have a dozen specimens of a much smaller form that appears to represent *D. tigrina* Bayer.

Finally, during the period of preparation of this manuscript the writer, temporarily immobilized by a broken ankle, was passing the time picking out well-preserved specimens present in the smaller sieve fractions saved from some of the Tulane field collections. To his amazement he noted a specimen of *Dimya* in the first "spread" of material from the Red Bluff Clay, lower Oligocene, of Mississippi (locality TU 226). This stimulated a careful examination of all material from that site with the result that more than 140 specimens were found. David Dockery, of the Mississippi Geologic Survey, found 178 additional specimens in his collections from the Red Bluff as exposed on Sand Branch Creek, Mississippi (TU 1291), and subsequent collecting from these and adjacent localities added an additional 354 specimens of this new species, which is herein named *Dimya rufaripa.*

Species referred to the genus *Dimya* have a more-or-less inequilateral, inequivalved shell that is made variable in shape by its sessile habit; the right valve, which is attached to some foreign object, is slightly larger than the left that fits inside its outer edge. Both valves have the outer layers composed of a micaceous-appearing substance, pearly white in color in Recent species, that was described as "nacreous" by Dall (1886, p. 228). The inner, visceral area of the valves is formed of a porcellanous material that is most notably developed inside of the pallial line but which extends in an apparently thinner glaze to a line of small pits that often are prolonged inward on the surface as rather strongly marked, radiately subparallel wrinkles. These, according to Dall (1886, p. 229), are "due to the papillae on the mantle-edge which are strongest at their distal ends, and which there form a narrow band of elevated waves and grooves which borders the mantle cavity of the shell." In some of the smaller shelled species, and in the more immature individuals of larger ones, these wrinkles may continue across the visceral area almost up to the hinge (see pl. 1, fig. 5; pl. 2, fig. 6). The marginal area between the line of pits and the pallial line tends to become a raised ridge dorsally toward the hinge area, with the shell falling away rather sharply toward the median part of the visceral area and more gently laterally toward the valve margins. These ridges are most strongly developed on the left (free) valve, but in both valves the pits or wrinkles of the marginal area extend up along the crests of the ridges, where they tend to be more strongly developed than in the ventral portions.

Most distinctive, however, are the scars of the adductor muscles. The anterior one is single, elongate-elliptical in shape, and well impressed along the antero-dorsad portion of the entire pallial line. The posterior scars consist of two subequal, ovate, and closely adjacent impressions that are somewhat more ventral in position than is the anterior one and also are inside of the pallial line.

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*Bibliographic references for all species may be found in the list that is appended to the text of this paper.

The hinge is marked by a resilium situated in a small, triangular, pit-like socket under the cavity of the low and inconspicuous umbo. This socket is margined in the right valve of larger shelled species by slightly raised and roughened borders that appear to represent feebly developed crura and fit between the rounded upper surface of the resilial socket and the extended dorsal ends of the raised lateral ridges of the left valves (see pl. 2, figs. 1b, 2a; pl. 3, figs. 5, 7b). In smaller shelled species, and in immature individuals of the larger ones, the raised lateral ridges are proportionately less developed and do not impinge upon the dorsal area, leaving a transversely striated "hinge-line" that is bisected by the resilial pit with the marginal "crura" very weakly developed. Dall (1886, p. 228) says of *D. argentea,* the "ligament is hardly perceptible, linear, nearly as long as the hinge-line," and Bayer (1971, p. 223), in his description of *D. tigrina,* says: "The thin, linear external ligament is visible along the whole hinge line." This feature is usually not preserved in the fossil specimens, apparently because the valve is so thinned along its area of attachment that the outer layers are easily broken away.

As noted by Yonge (1975, p. 549), the presence of both external and internal ligaments is a character that readily distinguishes the Dimyidae from the Pectinidae and Spondylidae. This same condition occurs, in somewhat modified form, in the Plicatulidae and both the latter family groups also agree in lacking a foot — present in the pectinids and spondylids. These features have led Yonge to propose that the Dimyidae and Plicatulidae be united in a superfamily Plicatulacea, separated from the Pectinacea to which both previously have been referred. However, under the Rules of Zoological Nomenclature (Article 36) the superfamily name must be Dimyacea and attributed to Fischer, 1886, although it was first used as of superfamily rank by Pilsbry (1922, p. 413).

The genus *Dimya* appears to have been developed from the genus *Dimyodon* "Munier-Chalmas" Fischer, 1886 (p. 937), with the type species (by monotypy) *D. schlumbergeri* "Munier-Chalmas" Fischer, from the Bathonian of Herouvillette, France. This latter genus differs primarily in having single anterior and posterior adductor scars, both of which are located adjacent to the pallial line. The cardinal crura are also somewhat more strongly developed and are striated. *Dimyodon* appears to be primarily Mesozoic in its distribution, having been reported in Europe from the upper Triassic (*D. richthofeni* Bittner, 1895), the Jurassic (*D. schlumbergeri*), and the Cretaceous (*"Ostrea" nilssoni* Hagenow, 1842; *D. böhmi* Stolley, 1892; *D. costatus* Grönwall, 1900, etc.). *Dimyodon nilssoni* also has been reported as occurring in the Upper Cretaceous of the Northern Range of Trinidad (Trechmann, 1935, p. 173) and it seems almost certain that *"Dimya" subrotunda* Felix, 1891, from the Neocomian (Lower Cretaceous) near Tehuacan, Puebla, Mexico, also is to be referred to *Dimyodon,* rather than to *Dimya.* The original illustrations are not adequate to permit any definite conclusions, but the description mentions *a* muscle scar on each side of the valve *on* a lineation "which perhaps represents a mantle impression" (freely translated), a feature that, as noted above, is distinctive of *Dimyodon.* This genus persists into the Paleogene in Europe, for the illustrations of *Dimyodon similis* von Koenen, 1893, and especially also those of the same species given in Sokolow (1905, p. 48 [Russian], 80 [German], text fig. 2, pl. 12, figs. 14a-c, 15a-c, 16a, b; pl. 13, figs. 3a, b) from the Lattorfian (lower Oligocene) of Germany and the Ukraine, respectively, attest to the accuracy of the generic determination, although Zelinskaya *et al.* (1968, p. 53, pl. 14, fig. 12) refer the species to *Deuteromya* Cossmann (=*Dimya*) and cite the age as upper Eocene. A subspecies, *D. similis interstricta* Noszky, 1939, has been described from the Rupelian, middle Oligocene, of Hungary.

"Dimyodon" storrsi J. P. Smith, 1927, from the upper Triassic Hosselkus Limestone of California, was identified as *Dimyodon* on the basis of the shape and ornamentation, the hinge and interior of the valves being unknown, but according to Smith "it has a strong similarity to *Dimyodon intustriatum* Emmrich *[sic],* of the Rhaetic beds of Austria. . ." Cox and Hertlein in the *Treatise on Invertebrate Paleontology* (p. N378), note that *Ostrea intusstriata* Emmrich, 1853, is the type of species of *Dimyopsis* Bittner (1895, p. 219), which genus they consider a synonym of *Atreta* Ettalon, 1862, assigned to the family Plicat-

ulidae. Species referred to *Atreta* are externally very similar to those of *Dimyodon* but differ in being monomyarian. Hence the systematic position of *D. storrsi* must be considered as uncertain until the nature of its internal structures can be determined.

Stratigraphic range — The genus *Dimya* has been reported as occurring in the Upper Cretaceous of North Africa — *D. libyca* Quaas, 1902, and *D. checchiai* Serra, 1936. Examination of the original illustrations suggests that both species are to be referred to *Dimyodon*. *Dimya* has been reported from the Paleocene of Belgium, questionably from the "Poudingue de Ciply" by Vincent, 1930, as "*Dimya* ? sp.?", and more definitely from the "Calcaire de Mons" by Glibert and Van de Poel, 1973, as "*Dimya* sp. ?."

The genus appears to have "flowered" during the Eocene, especially in the region of the Tethyan seaway. The writer has found records of eleven Eurasian Tethyan species that have been referred to *Dimya* (see appendix listing, this paper); some of these forms may well prove to be synonyms of one or another in the list. They are from Spain, southwestern France and the Paris Basin, northern Italy, the northern Alps of Austria and Bavaria, Bulgaria, Libya, Egypt, the Ukraine and western Punjab, India. During the middle Eocene the genus reached the United States (this paper) and New Zealand (undescribed species, Maxwell, 1978, p. 16). The upper Eocene is represented in South Australia by *D. sigillata* Tate, and in New Zealand by *D. westonensis* Maxwell.

Following the Eocene there is a marked decline in the number of recorded fossil species. Prior to this report only one species and a subspecies have been reported from the Oligocene: *D. fragilis* von Koenen, 1893, described from the Lattorfian (lower Oligocene) of Germany and also reported from the same horizon in the Ukraine (Sokolow, 1905, p. 47, pl. 13, figs. 9-12); a subspecies *D. f. punctata* Noszky, 1939 — as "*Dymia*"*[sic]*, known from the Rupelian (middle Oligocene) of Hungary. The geologic age of *D. raulini* (Cossmann and Peyrot, 1914) — as *Deuteromya* — is reported as "*Helvetian*?," but the authors state that the stratigraphy at the type locality is so uncertain that all that can be said with assurance is that it is younger than D. *deshayesiana* Rouault, 1850, which is Lutetian (middle Eocene) in age.

Species of known Miocene and Pliocene age are confined, in Europe, to the Italian sections. Two were described in 1897 as subspecies of the Oligocene *D. fragilis* von Koenen — *D. f. miopliocenica* Sacco (Helvetian, middle Miocene, to Plaisancian, lower Pliocene) and *D. f. crassiplicata* Sacco (Tortonian, upper Miocene). A third form, *D. extenuiplicata* (Sacco) (new name for *Ostrea tenuiplicata* Seguenza, 1879, *non* Sowerby), reported as ranging from the Aquitainian (early Miocene) to the Astian (lower Pliocene) of Calabria, may prove to be a synonym of *D. fragilis miopliocenica*. In his discussion of the latter, Sacco (1897, p. 41) noted that Seguenza had described and figured a similar form under the preoccupied name of *Ostrea tenuiplicata* but added that, if the description and figures [exterior only] were accurate, the form lacks the characteristic double muscle impressions of *Dimya*. He apparently had overlooked the discussion by Dall (1886, p. 231) who wrote: "The figure of *Ostrea tenuiplicata* of Seguenza resembled *Dimya* so much in its exterior that I requested Professor Seguenza to examine the interior and inform me of the character of the muscle impressions. He did so, and also most kindly sent me two valves which determine the correctness of my suspicions. The shell is an undoubted *Dimya*."

The known Mio-Pliocene record, exclusive of Europe, consists only of *D. dissimilis* Tate, 1886, uppermost Oligocene (?) to Lower Pliocene, South Australia; *D. kaiparaensis* Laws, 1944, from the (?) lower Miocene of New Zealand; and of *D. grandis* Dall and *D. g. divaricata* Dall, 1896, from the upper Miocene of the Dominican Republic. The Pleistocene forms described herein are, insofar as the writer has been able to learn, the first reported from that epoch.

In contrast to the sparsity of the dimyids in the Oligocene-Pleistocene interval is their relative abundance in the Recent faunas. There are at least 13 described Recent forms that have been referred to the genus *Dimya* (two of these, *D. radiata* and *D. r. takii* both of Kuroda, have been placed in the synonymy of *D. filipina* Bartsch by Habe, 1971, p. 330). These 13

named forms include two from the western Atlantic Ocean. (*D. argentea* Dall, 1886, and *D. tigrina* Bayer, 1971), two from the eastern Pacific Ocean (*D. californiana* Berry, 1936, and *D. coralliotis* Berry, 1944), two from the Hawaiian Islands (*D. mimula* and *D. molokaia,* both of Dall, Bartsch and Rehder, 1938), and seven from the western Pacific area, two of which, as noted above, may be synonyms of a third form. These seven include *D. corrugata* Hedley, 1902 (type of *Dimyarina* Iredale, 1936) from off New South Wales, Australia; *D. maoria* Powell, 1937, from off Three Kings Islands, North Island, New Zealand; *D. lima* Bartsch, 1913, from the Philippines and Indonesia; *D. filipina* Bartsch, 1913, from the Philippines and, if Habe is correct in his synonymizing of *D. radiata* and *D. r. takii,* from off southern Japan; and *D. japonica* Habe, 1971, from south and central Japan.

Curiously there appear to be no known Recent species from the eastern Atlantic Ocean, the Mediterranean Sea or the Indian Ocean, all of which are more or less adjacent to the region of the early Tertiary Tethyan seas in which the genus had its first "flowering."

Ecologic Observations — Available bathymetric data indicate that the majority of the Recent species are inhabitants of outer shelf and continental slope depths. The average of the 47 dredging records with depth information available for dimyid species is 311 meters. There is, of course, variation in this factor between different species; the average depth of the 19 stations from which such data on the occurrence of *D. argentea* has been reported is 354.6 meters, while the types of *D. tigrina* Bayer, the other known western Atlantic species, were dredged between 75 and 79 meters. The species with the deepest average occurrence appears to be *D. lima* Bartsch in which the average of ten records is 429 meters; however, Bartsch (1913, p. 307) questions one record in which the depth (83 fathoms) was taken from a chart rather than from a sounding. This appears to be too shallow relative to the normal range of the giant limid species on which the *Dimya* was growing and is less than one half the depth of the next shallower record for *D. lima.* If this station be ignored, the average depth for *D. lima* is 459.5 meters.

In the opinion of the writer the apparent disappearance and scarcity of species of *Dimya* after its Eocene flowering is to be explained as the result of its migration to deeper waters in the face of competition from more "aggressive" shallow-water species.

Only a few records are available as to bottom temperature at stations from which species of *Dimya* have been collected. Five of these are cited by Dall (1886, p. 231) for *Dimya argentea;* these range from 54.5°F at 248 fathoms (453.5 meters) off St. Croix, Virgin Islands, to 70.7°F at 73 fathoms (133.5 meters) off Barbados. The average for all five stations is 61.4°F. There are eight records cited by Bartsch (1913, pp. 306-7) for *D. lima* which, as noted above, has the deepest average occurrence. The temperatures at these stations ranged from 47.4°F to 63.6°, the average being 54.7°. The coolest temperature occurred at the most northerly station, 13°53′ N latitude, with the warmest at one of the more southern ones located at 6°11′50″ N. Of special interest is the fact that for five stations, intermediate in position between 8°36′26″ and 9°31′50″N., the range in temperature was only one degree Fahrenheit — from 53.3° to 54.3°, even though the depth range was from 175 fathoms (320 meters) to 432 fathoms (790 meters).

Single locality records are available for three other species: *D. filipina* Bartsch — 63.1°F, depth 108 fathoms (192 meters); *D. mimula* Dall, Bartsch and Rehder — 65.5°F, 127-130 fathoms (ca. 235 meters) and *D. molokaia* Dall, Bartsch and Rehder — 72°F, 66-96 fathoms (ca. 148 meters). Both of the latter species were described from the Hawaiian Islands. These few records are too insufficient to permit any conclusions save the fact that species of the genus *Dimya* are inhabitants of only the warmer portions of the outer shelf and slope waters.

III. ACKNOWLEDGMENTS

The writer wishes to record his deep appreciation of the kindness of Mr. James Allen of Alexandria, Louisiana, for sending the specimens that stimulated this study, and to Mr. David Dockery, a graduate student at this university who is studying the bivalve faunas of the Vicksburg Group, Oligocene, for the loan of 178 spec-

imens of the form here described as *Dimya rufaripa* collected from the Red Bluff Clay on Sand Branch in Mississippi. He is also indebted to Dr. Myra Keen, Stanford University (Emeritus), whose constructive criticisms and suggestions were most helpful.

IV. SYSTEMATIC PALEONTOLOGY

Superfamily DIMYACEA Fischer, 1886 [Pilsbry, 1922]
Family DIMYIDAE Fischer, 1886
Genus DIMYA Rouault, 1850*

Dimya ROUAULT, 1850, Mém. Soc. Géol. France, (ser. 2) v. 3, pt. 2, p. 470 (Mém. 7, p. 14; 1848 ?)

Margariona ("Dall MS") KOBELT, 1882, Nachrbl. Deutsch. Malakozool. Gesell., v. 14, nos. 11-12, p. 186 [no species cited; put in synonymy of *Dimya* by Dall, 1886].

Deuteromya COSSMANN, 1903, Rev. Crit. Paléozool., v. 7, p. 68 [unnecessary new name for *Dimya* Rouault, *non Dimya* Menke, 1830, a suborder name that does not pre-occupy a genus-group name — see ICZN Art. 52].

? *Dimyarina* IREDALE, 1936, Rec. Australian Mus., v. 19, p. 269 [type species: *Dimya corrugata* Hedley, 1902].

Type specis, by monotypy, *Dimya deshayesiana* Rouault, 1850, Mém. Soc. Géol. France, (ser. 2) v. 3, pt. 2, p. 471, pl. 15, figs. 3, 3a, 3b. Eocene, Bos d'Arros, Southern Aquitaine, France.

DIMYA ALLENI H. E. Vokes, n. sp.
Plate 1, figures 1-5

Description: Shell small, averaging about 5 mm in length — the largest entire valve being but 6.1 mm high (one broken specimen suggesting a possible maximum height of about 8 mm); round to roundly ovate in outline, attached by the right valve. Left valve smooth, usually with a raised boss-like elevation above the attachment surface, occasional specimens revealing a few scattered, broadly rounded microscopic riblets mainly toward the posterior lateral margin. Shell material with a micaceous appearance externally but with a relatively thick, white chalky coating internally over the visceral area. Hinge-line variable in length, depending upon the attachment area, but tending to be moderately elongate and occasionally sub-auriculate, with the triangular capping over the small resilial pit subcentral and, in the left valve, topped by a slightly projecting, very small umbo. The row of radial markings on the outer edge of the visceral area usually consisting in the left valve of slightly elongate radial pits that appear to have received corresponding low radial ridges on the right; however, considerable variation occurs even within the same specimen. Anterior adductor scar elongate, elliptical, impressed on the pallial line dorsal to the mid-height of the visceral area of the valve; posterior scars duplicate, the two units being relatively large for the size of the valve, rounded and located more or less diagonally transverse, with the more ventral scar situated just inside the weakly marked pallial line.

Type locality: Sabine River, Columbus, Sabine Parish, Louisiana.

Occurrence: Cook Mountain Formation, middle Eocene.

Holotype, USNM 263960; height 6.4 mm, length 6.2 mm, diameter (left valve) ca. 1.2 mm. (Plate 1, fig. 2)

Paratype A, USNM 263959; height 6.0 mm, length 6.3 mm, diameter (right valve) ca. 1.6 mm. (Plate 1, fig. 1)

Paratype B, USNM 263961; height 5.6 mm, length 5.5 mm, diameter (left valve) ca. 1.3 mm. (Plate 1, fig. 3)

Paratype C, USNM 263962; height 5.1 mm, length 6.0 mm, diameter (left valve) ca. 1.2 mm. (Plate 1, fig. 4)

Paratype D, USNM 263963; height 7.2 mm, length 6.9 mm, diameter (right valve) ca. 1.1 mm. (Plate 1, fig. 5)

Remarks: Dimya alleni, the oldest presently known western Atlantic Tertiary dimyid, may be distinguished from the other known species from this region by its small size and essentially smooth surface lacking the radial ornament that is well-developed on the comparably small lower Oligocene *D. rufaripa,* n. sp., or the Pleistocene and Recent *D. tigrina* Bayer. Available illustrations of the middle Eocene *D. deshayesiana* Rouault, the type species of the genus, reveal a finely ribbed shell that is about twice the size of the present species and has the paired posterior adductor scars located proportionately much higher in the valve.

This new species is named in honor of James A. Allen of Alexandria, Louisiana, an avid collector of the lower Tertiary fos-

*According to Dall (1886, p. 228, fft.) "Rouault's paper was read in 1847, but seems to have been published in 1848 [as a separate], while the volume appeared in 1849." Sherborn, however, gives the date as 1850. Fischer, (1886, p. 936) cites it as of 1859, an obvious typographical error that has been copied by a number of subsequent authors.

sil faunas of this State, who first noted the unique characteristics of the specimens in his collection.

All specimens were collected from outcrops of the Cook Mountain formation, middle Eocene (Claibornian), located in the banks of the Sabine River near Columbus, Louisiana, prior to the flooding of the area by the waters of the Toledo Bend Reservoir.

DIMYA RUFARIPA H. E. Vokes, n. sp.

Plate 1, figures 6-9

Description: Shell small, averaging about 5 mm in height — the largest specimen being 7.2 mm high and 8.3 long; round to roundly ovate, attached by the right valve; left valve smaller, fitting inside the outer edges of the right. Both valves, outside of the area of attachment, ornamented by fine, rounded, divaricating radial ribs with round-bottomed interspaces of almost equal width; the individual ribs essentially of equal strength from their first appearance at the edge of the attachment area to the valve margin, with each rib divaricating repeatedly to accommodate the increased width toward the marginal area. The attachment area of the right valve tending to mirror the surface ornament of the object to which it was cemented; that of the left smooth and generally somewhat raised to form a boss-like elevation from the lower, outer edges of which the radial ornament trends across a lower and flatter marginal area. The shell material having, especially in the marginal areas, a distinctly micaceous appearance. Hinge-line variable in length, depending upon nature of attachment, generally short, with a small umbonal angle immediately above the triangular capping of the small, ovate resilial pit. Visceral area with a white, porcellaneous coating, strongest inside of the entire pallial line; unlike the other species here discussed, in the area between the pallial line and the row of pits or low ridges seemingly not covered with the porcellaneous coating, the area being almost dark gray to black in color and smooth except for widely spaced, low, rounded, irregularly radial riblets that cross from the outer row of ridges and pits to the inner edge of the coated portion of the visceral area. The riblets becoming much more numerous and closely adjacent as they enter upon the raised crura-like dorsal margins of the area. In the left valve the outer row characteristically appearing to have been marked by narrow grooves that divide a small raised area into two closely approximate ridges, the crests of the ridged margins of the right being received in the inter-ridge grooves of the left. External to the outer row of ridges the shell margins smooth in the right valve up to the extreme outer edge, where the thinned shell material becomes slightly corrugated by the ends of the external ribs; in the left valve the ventral margins beyond the outer row of ridges and grooves tending to be reflexed to fit inside the more concave interior of the right. Anterior adductor scar elongate-elliptical, located on the pallial line moderately high on the valve and well impressed; posterior scar duplicate, the two units being dorso-ventral to each other, both situated well within the pallial line.

Type locality: TU 226, Chickasawhay River, at Hiwannee, Wayne Co., Mississippi.

Occurrence: Red Bluff Clay, lower Oligocene.

Holotype, USNM 263965; height 6.5 mm, length 6.4 mm, diameter (right valve) 2.9 mm. (Plate 1, fig. 7)

Paratype A, USNM 263964; height 6.9 mm, length 7.3 mm, diameter (right valve) 2.1 mm. (Plate 1, fig. 6)

Paratype B, USNM 263966; height 5.8 mm, length 5.0 mm, diameter (left valve) 0.8 mm. (Plate 1, fig. 8)

Paratype C, USNM 263967; height 5.2 mm, length 5.7 mm, diameter (left valve) 1.1 mm. (Plate 1, fig. 9)

All specimens from locality TU 226, Red Bluff Clay, lower Oligocene.

Remarks: Dimya rufaripa, n. sp., may be distinguished by its small size and the relatively fine, divaricate external radial ribbing. The older *D. alleni,* although similarly small, is almost smooth externally and *D. tigrina,* which is a little larger, has a somewhat more irregular radial ornament that is frilled by raised, concentric growth lamellae. The European lower Oligocene *D. fragilis* von Koenen (1893, p. 1065, pl. 69, figs. 5a-c, 6a-c), similarly small, is almost smooth, lacking the divaricate radial ornament.

The above description is based upon 679 specimens from five localities in the Red Bluff Clay, lower Oligocene of eastern Mississippi. It is of interest to note that of the 250 specimens in which the right valve was found attached to identifiable shell substrate, 240 were on valves or fragments of valves of pelecypod species; only ten were on fragments of a weakly ornamented gastropod and not one specimen was found attached to any of the rather abundant corals. Almost one-half of those attached to pelecypods (122 of 250) were found on the relatively smooth upper valves of ostreids, the remainder were on species of *Spondylus, Astarte, Corbula, Protocardia,* etc.

The specific name is in reference to its occurrence in the Red Bluff Clay (*rufus* = red; *ripa* = river bank). Specimens in the collection are from TU localities 226, 642, 1288, and 1289, on the Chickasawhay River near Hiwannee and from Sand Branch Creek, Wayne Co., Mississippi, TU locality 1291.

DIMYA GRANDIS Dall

Plate 2, figures 1-7

Dimya grandis Dall, 1896, *in* GUPPY and DALL, U.S. Natl. Mus., Proc., v. 19, no. 1110, p. 328 ["Oligocene of the Portrero, Rio Amina, Santo Domingo, Bland."] Dall, 1898, Wagner Free Inst. Sci., Trans., v. 3, pt. 4, p. 764, pl. 35, fig. 8; DALL, 1915, *in* SCHUCHERT *et al.*, U.S. Natl. Mus., Bull. 53, pt. 1, p. 226 [Cotypes 113799]; PILSBRY, 1922, Acad. Nat. Sci. Phila., Proc., v. 73, p. 413.

Dall described this, the only previously reported fossil species from the western Atlantic faunas, as follows:

"Shell large for the genus, ostreiform, attached by the right valve; externally smooth or (in the variety *divaricata*) rather strongly sculptured with close-set dichotomous radiating ribs; internally smooth and nacreous near the edges; the visceral area with a porcellanous, finely granulated coat, posterior adductor leaving a duplex scar, as in *D. argentea* Dall; anterior scar single, small, close to the pallial border and high up in the valve; pallial area bordered by a line of minute, fringe-like, short grooves; cardinal crura raised on each side of the small, subtriangular socket for the resilium, behind which they join, forming in the right valve a keystone-shaped projection which fits inside the pair on the left valve. Alt. 32, lat. 30 mm.

"The genus *Dimyodon*, Munier-Chalmas, is characterized chiefly by its undivided posterior adductor scar, the tooth-like crura being present though feeble in the typical *Dimya*. The present form has the scars of *Dimya* and well-developed crura. . . ."

The only previously published illustration of this species was that of Dall (1898, pl. 35, fig. 8), who gave a view of the interior of an upper, left valve. The caption for this figure includes: "lon. 33 mm." The height, as measured on the illustration is 30.5 mm, and it must be assumed that the figured specimen is not that whose meas-

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PLATE 1

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1-5. *Dimya alleni* H. E. Vokes, n. sp. (× 5) 38

1. Paratype A, USNM 263959; height 6.0 mm, length 6.3 mm, diameter (right valve) ca. 1.6 mm.
2. Holotype, USNM 263960; height 6.4 mm, length 6.2 mm, diameter (left valve) ca. 1.2 mm.
3. Paratype B, USNM 263961; height 5.6 mm, length 5.5 mm, diameter (left valve) ca. 1.3 mm.
4. Paratype C, USNM 263962; height 5.1 mm, length 6.0 mm, diameter (left valve) ca. 1.2 mm.
5. Paratype D, USNM 263963; height 7.2 mm, length 6.9 mm, diameter (right valve) ca. 1.1 mm.

All specimens from Cook Mountain Formation, Claibornian, middle Eocene, from bank of Sabine River near Columbus, Louisiana.

6-9. *Dimya rufaripa* H. E. Vokes, n. sp. (× 6) 39

6. Paratype A, USNM 263964; height 6.9 mm, length 7.3 mm, diameter (right valve) 2.1 mm.
7. Holotype, USNM 263965; height 6.5 mm, length 6.4 mm, diameter (right valve) 2.9 mm.
8. Paratype B, USNM 263966; height 5.8 mm, length 5.0 mm, diameter (left valve) 0.8 mm.
9. Paratype C, USNM 263967; height 5.2 mm, length 5.7 mm, diameter (left valve) 1.1 mm.

All specimens from locality TU 226, Red Bluff Clay, lower Oligocene, Wayne County, Mississippi.

10. *Dimya* species (× 3) 49

USNM 263968; height 8.7 mm, length 10.2 mm.
Locality TU 705, Bowden Formation, lower Pleistocene, Bowden, Jamaica.

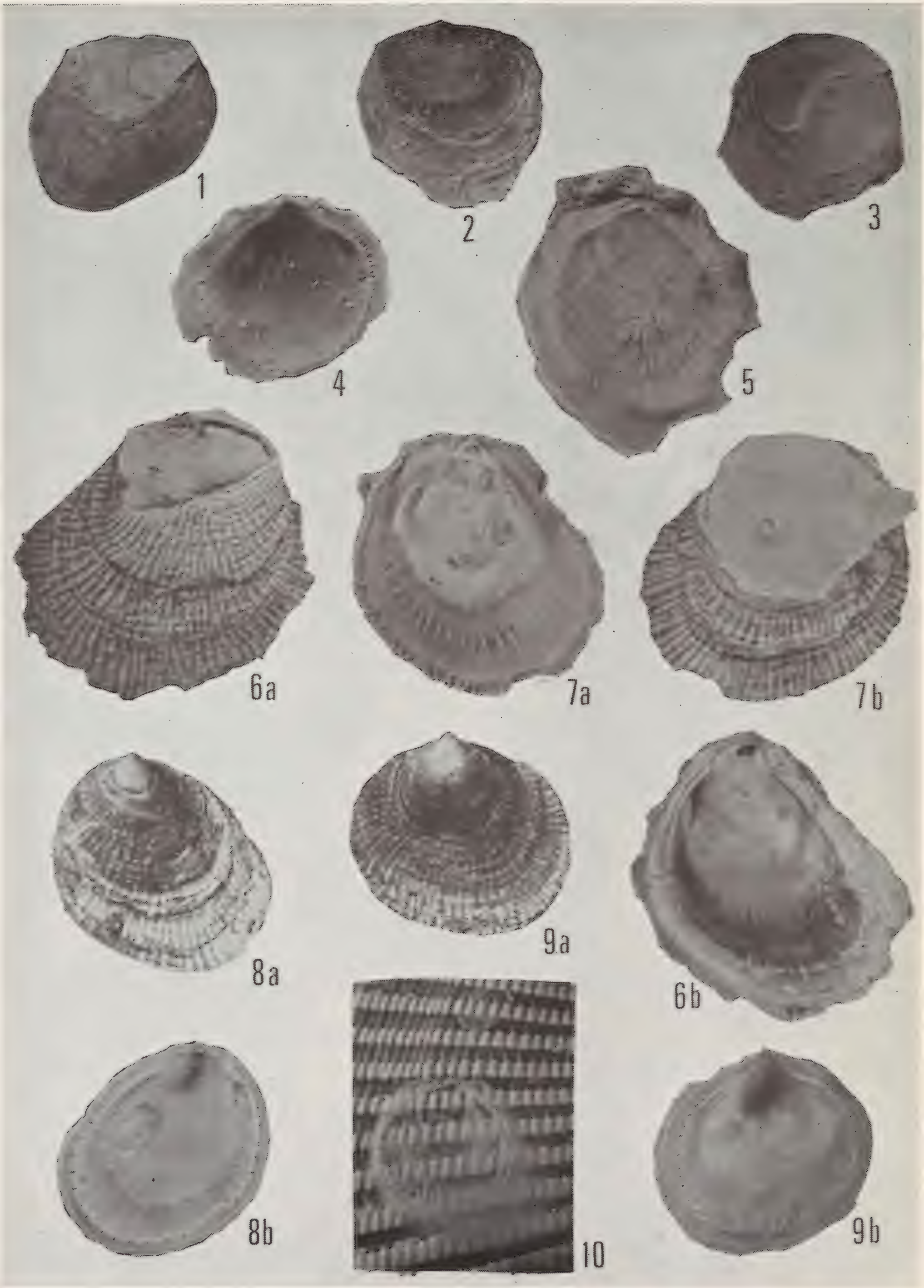

PLATE 1

urements were given by Dall in the original description for it is longer and slightly lower than the latter.

This well-named species appears to be the largest yet referred to *Dimya*. The writer has not had access to all published illustrations of species referred to the genus, but the average of the 43 measurements of other described species noted in the literature is: height 12.06 mm, length 12.13 mm. It must be added, however, that none of the 539 specimens of *D. grandis* (including 68 referrable to the variety *divaricata* Dall) in the Tulane University collections attain dimensions as large as those cited by Dall. Our largest specimen is a right valve from TU 1254, which is 31.8 mm high and 27.4 mm long; our largest topotype is 28 mm high and 27.4 mm long.

There seems to be a distinctive tendency for the inner margins of the left valve immediately adjacent to the procellanous visceral area to become raised, almost like enlarged crura, and to be "pinched in" a little below the hinge area (see pl. 2, figs. 1b, 4). This is not apparent in the right valves, and indeed, there is some basis for the suggestion that these enlarged areas of the left valves fit within the raised marginal areas of the right valves.

It is to be noted that of the 539 valves present in the Tulane University collections, only 68 show the radial ornamentation of the variety *divaricata*. In the majority of the individuals in our collections this ornament is rather weakly developed; the specimen here figured (pl. 2, fig. 7) is that valve on which ribbing is most prominently displayed.

Dall described this species from the "Oligocene of the Portrero [*sic*, = Potrero], Rio Amina, Santo Domingo." The strata exposed at this locality were subsequently referred to the Gurabo Formation of Maury (1919, p. 591) by Vaughan and Woodring (1921, *in* Vaughan *et al.*, p. 130 — USGS loc. 8516) who suggested (p. 100) a possible Helvetian, middle Miocene age for that formation. More recently, Seiglie and Cucurullo (1971), who studied, in part, the planktonic foraminiferal faunas of the Mao Adentro Limestone, which, according to Vaughan *et al.*, (1921, p. 74), "appears" to be gradational upon the Gurabo, assign a lowermost Pliocene, zone N-18, age to that formation; this would strongly suggest an upper Miocene age for the Gurabo deposits.

Dimya grandis and variety *divaricata* although rather widely distributed in the deeper water facies of the Gurabo Formation are abundantly represented at only one locality, TU locality 1254, from which we have 193 valves. At this site there were two lenticular units, apparently the result of turbidity flows, dipping eastwardly across a road cut. The maximum thickness of each unit was approximately 30 inches, but their total lengths could not be determined. These lenses contained a vast num-

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PLATE 2

Figures Page

1-6. *Dimya grandis* Dall 40
1. Topotype, USNM 263969 (× 2); height 28.0 mm, length 27.4 mm, diameter (left valve) 3.3 mm. Locality TU 1219.
2. Topotype, USNM 263970 (× 2); height 26.0 mm, length 26.9 mm, diameter (right valve) 5.0 mm. Locality TU 1219.
3. Topotype, USNM 263971 (× 2); height 15.2 mm, length 16.2 mm, diameter (right valve) 2.1 mm. Locality TU 1219.
4. Topotype, USNM 263972 (× 2); height 23.5 mm, length 21.6 mm, diameter (left valve) 2.9 mm. Locality TU 1219.
5. USNM 263973 (× 2.5); height 11.9 mm, length 13.4 mm, diameter (right valve) 5.5 mm. Locality TU 1210.
6. USNM 263974 (× 6); height 5.5 mm, length 5.5 mm diameter (immature left valve) 0.7 mm. Locality TU 1210.

7. *Dimya grandis* variety *divaricata* Dall (× 2) 40
Topotype, USNM 263975; height 18.0 mm, length 22.8 mm, diameter (right valve) 4.5 mm. Locality TU 1219.

All specimens from the Gurabo Formation, upper Miocene, Dominican Republic.

PLATE 2

ber of valves of *Dimya,* many of which were broken and only a few were found that were paired; in addition we collected several broken valves of a large *Amussium,* and three *Ostrea haitensis.* There were molds of other forms, both gastropods and bivalves, and, unfortunately, the inner aragonitic layers of the dimyids also had been removed by solution. Ten other localities have yielded fewer but better preserved specimens; included are 31 topotype valves from the Rio Amina near Potrero (TU 1219), seven from TU 1225 on an arroyo entering the Rio Mao, 35 from four localities (TU 1210, 1211, 1215, 1277) in bluffs along the Rio Gurabo, 142 from cuts on the road from Los Quemados to Sabaneta (TU 1209, 1279), 14 from a deep arroyo that crosses the Santiago/Janico road (1227), and one from a bluff on the Rio Verde near Santo Cerro (TU 1250). In addition, 116 juvenile (?) valves were secured from a small lense that appears to represent a turbidity flow, which transported shallower water material rich in foraminifera and small mollusks into the typical deeper water siltstone facies of the Gurabo Formation (loc. TU 1227A).

In view of this relatively wide distribution it is difficult to account for the fact that it has not been reported from collections made from this area before or since Dall's original description and illustration. It may well be, in view of the size of the shells and their more or less nondescript appearance that those specimens collected were considered, uncritically, to pertain to immature ostreids or plicatulids; indeed, Pilsbry (1922, p. 413) in his "Revision of W.M. Gabb's Tertiary Mollusca of Santo Domingo" notes that "three valves of the typical form and two of var. *divaricata* were found among unsorted oyster valves."

Figured topotype, USNM 263969; height 28.0 mm, length 27.4 mm, diameter (left valve) 3.3 mm; locality TU 1219. (Plate 2, fig. 1)

Figured topotype, USNM 263970; height 26.0 mm, length 26.9 mm, diameter (right valve) 5.0 mm; locality TU 1219. (Plate 2, fig. 2)

Figured topotype, USNM 263971; height 15.2 mm, length 16.2 mm, diameter (right valve) 2.1 mm; locality TU 1219. (Plate 2, fig. 3)

Figured topotype, USNM 263972; height 23.5 mm, length 21.6 mm, diameter (left valve) 2.9 mm; locality TU 1219. (Plate 2, fig. 4)

Figured specimen, USNM 263973; height 11.9 mm, length 13.4 mm, diameter (right valve) 5.5 mm; locality TU 1210. (Plate 2, fig. 5)

Figured specimen, USNM 263974; height 5.5 mm, length 5.5 mm, diameter (immature left valve) 0.7 mm; locality TU 1210. (Plate 2, fig. 6)

Figured topotype, *Dimya grandis* var. *divaricata,* USNM 263975; height 18.0 mm, length 22.8 mm, diameter (right valve) 4.5 mm; locality TU 1219. (Plate 2, fig. 7)

DIMYA FIMBRICOSTATA
H. E. Vokes, n. sp.
Plate 3, figures 1-7; Plate 4, figures 1-4

[?] *Ostrea borealis* ? Lamarck. GABB, 1881, Acad. Nat. Sci. Phila., Jour., (ser. 2) v. 8, p. 380.

Description: Shell relatively large for the genus, more or less irregular in shape, depend-

PLATE 3

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1-7. *Dimya fimbricostata* H. E. Vokes, n. sp. 44

1. Holotype, USNM 263976 (× 2.5); height 23.6 mm, length 25.5 mm, diameter (paired valves) 10.5 mm. Locality TU 954.
2. Paratype A, USNM 263977 (× 2.5); height 20.5 mm, length 23.4 mm, diameter (right valve) 5.5 mm. Locality TU 954.
3. Paratype I, USNM 263978 (× 2.8); height 10.7 mm, length 12.6 mm, diameter (left valve) 2.5 mm. Locality TU 1240.
4. Paratype F, USNM 263979 (× 2.5); height 20.4 mm, length 18.0 mm, diameter (left valve) 5.1 mm. Locality 954.
5. Paratype G, USNM 263980 (× 2); height 20.1 mm, length 26.7 mm, diameter (right valve) 7.2 mm. Locality TU 954.
6. Paratype C, USNM 263981 (× 2); height 22.6 mm, length 23.5 mm, diameter (right valve) 8.9 mm. Locality TU 954.
7. Paratype J, USNM 263982 (× 2); height 21.4 mm, length 24.9 mm, diameter (left valve) 5.5 mm. Locality TU 1240.

All specimens from Moín Formation, Pleistocene, Costa Rica.

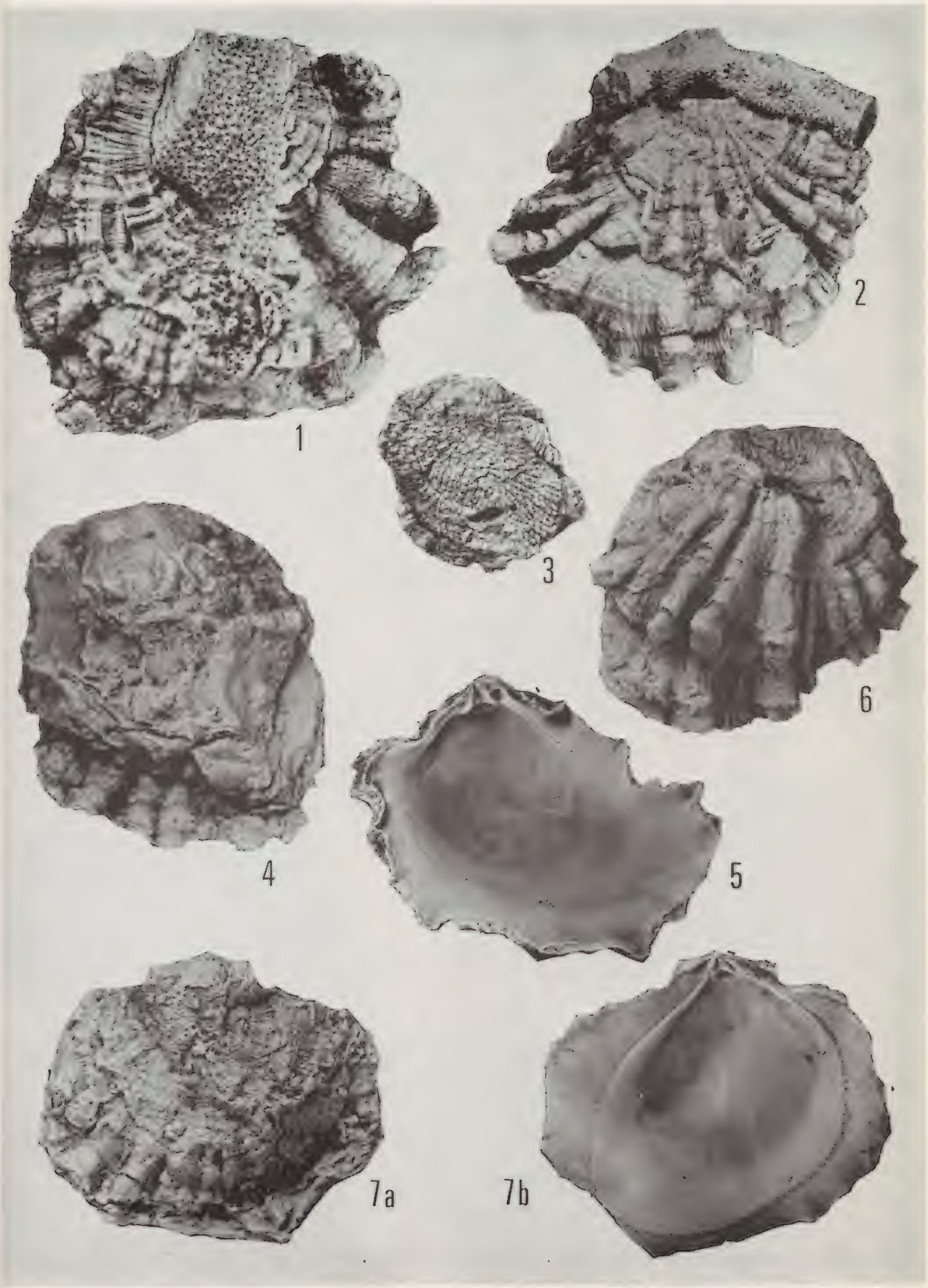

PLATE 3

ing upon the nature of the attachment area, but usually roundly ovate and tending to be slightly produced posteriorly. Right valve attached to substrate, slightly larger than the left valve that fits inside of its outer edge; exterior of both valves rugose, with strong costae developing marginally from the area of attachment on the right valve and from a corresponding medially irregular roughened area on the left. Both the costae, which tend to plicate the thinner valve margins slightly, and the interspaces ornamented with finer, irregular, more or less radial costellae, the whole being fimbriated by thin, raised, concentric growth lamellae and occasional rugosities from interruptions of growth. Hinge-line variable according to area of attachment, occasionally slightly auriculate on one side or the other, but never relatively long and straight as in *D. argentea* Dall or *D. tigrina* Bayer. Hinge-line in most specimens marked by a slight projection at the site of triangular capping of the small resilial socket; the outer edges of this capping on the right valve raised to form slender cardinal crura, which do not quite meet at the apex of the triangle. These crura fitting into narrow, relatively deep sockets that margin the capping of the resilifer in the left valve; elongate grooves laterally adjacent to the crura of the right valve receiving the apical ends of enlarged marginal ridges in the left valve, which are formed ventrally between the pallial line and the row of impressed pits at the outer limit of the visceral area. Inner margins of the valve of a rather micaceous appearance; smooth, except for the suggestion of plications developed by the strong surficial costae. Visceral area with a porcellaneous coating that appears to be most strongly developed in the area inside of the entire pallial line; the thinner, outer part of the coating exterior to the pallial line margined, laterally, by a row of small pits or short, low, and narrow radial ridges, extending inwardly in many specimens to the pallial line as progressively weakened, inconspicuous and irregularly radial ridges. Muscle scars of the type characteristic of the genus. The anterior scar, closer to the hinge area than the doubled posterior one, appearing to straddle or terminate the pallial line, elliptical in shape and, especially on the right valve, deeply impressed. Posterior scars distinctly bilobed, located adjacent to but inside of the pallial line; the outer and larger lobe tending to be more impressed than the smaller inner one.

Type locality: TU 954, hill cut behind Standard Fruit Company's box factory, just west of cemetery at Pueblo Nuevo, about 2 km west of Puerto Limón, Costa Rica.

Occurrence: Moín Formation, lower and middle Pleistocene; Costa Rica.

Holotype, USNM 263976; height 23.6 mm, length 25.5 mm, diameter (paired valves) 10.5 mm; locality TU 954. (Plate 3, fig. 1)

Paratype A, USNM 263977; height 20.5 mm, length 23.4 mm, diameter (right valve) 5.5 mm; locality TU 954. (Plate 3, fig. 2)

Paratype B, USNM 263984; height 21.6 mm, length 23.0 mm, diameter (right valve) 9.6 mm; locality TU 954. (Plate 4, fig. 2)

Paratype C, USNM 263981; height 22.6 mm, length 23.5 mm, diameter (right valve) 8.9 mm; locality TU 954. (Plate 3, fig. 6)

Paratype D, USNM 263983; height 22.3 mm, length 25.9 mm, diameter (left valve) 4.5 mm; locality TU 954. (Plate 4, fig. 1)

Paratype E, USNM 263986; height 21.6 mm, length 17.3 mm, diameter (left valve) 4.1 mm; locality TU 954. (Plate 4, fig. 4)

PLATE 4

Figures Page

1-4. *Dimya fimbricostata* H. E. Vokes, n. sp. (× 2.5) 44
1. Paratype D, USNM 263983; height 22.3 mm, length 25.9 mm, diameter (left valve) 4.5 mm. Locality TU 954.
2. Paratype B, USNM 263984; height 21.6 mm, length 23.0 mm, diameter (right valve) 9.6 mm. Locality TU 954.
3. Paratype H, USNM 263985; height 19.7 mm, length 16.6 mm, diameter (left valve) 4.0 mm. Locality TU 1240.
4. Paratype E, USNM 263986; height 21.6 mm, length 17.3 mm, diameter (left valve) 4.1 mm. Locality TU 954.

5-7. *Dimya tigrina* Bayer (× 8) 48
5. USNM 263987; height 4.4 mm, length 5.2 mm (right valve). Locality TU 953.
6. USNM 263988; height 6.3 mm, length (incomplete) 6.3 mm (right valve). Locality 953.
7. USNM 263989; height 5.7 mm, length 6.6 mm (left valve). Locality TU 953.

All specimens from Moín Formation, Pleistocene, Costa Rica.

PLATE 4

Paratype F, USNM 263979; height 20.4 mm, length 18.0 mm, diameter (left valve) 5.1 mm; locality TU 954. (Plate 3, fig. 4)

Paratype G, USNM 263980; height 20.1 mm, length 26.7 mm, diameter (right valve) 7.2 mm; locality TU 954. (Plate 3, fig. 5)

Paratype H, USNM 263985; height 19.7 mm, length 16.6 mm, diameter (left valve) 4.0 mm; locality TU 1240. (Plate 4, fig. 3)

Paratype I, USNM 263978; height 10.7 mm, length 12.6 mm, diameter (left valve) 2.5 mm; locality TU 1240. (Plate 3, fig. 3)

Paratype J, USNM 263982; height 21.4 mm, length 24.9 mm, diameter (left valve) 5.5 mm; locality TU 1240. (Plate 3, fig. 7)

Remarks: The 404 specimens upon which the above description has been based reveal a wide variation in shape and form depending upon the nature of the area to which the right valve had been attached. Most of the specimens clearly were attached to branching corals (see pl. 3, figure 2). Others show surface scars that can only be attributed to bryozoans, which may have been coating the surfaces of corals or small molluscan shells. Some clearly were attached to each other and a few to gastropods (*Cypraea, Conus, Strombus,* etc.).

The strongly costate, rugose surface ornamentation is the most distinctive feature of this new species. Some of the more strongly ornamented specimens of *D. grandis divaricata* Dall are not unlike the more weakly ornamented forms of the present species, but none of the latter ever have the relatively smooth external surface that is characteristic of the majority of the specimens of *D. grandis,* nor do they reveal the peculiar "pinched in" condition of the marginal ridges just below the hinge line on the left valves that may be seen in the Dominican Miocene species.

Ninety of the specimens upon which this species is based were collected at TU locality 954 from strata exposed in the hill cut immediately behind the Standard Fruit Company's box factory just west of the cemetery at Pueblo Nuevo, a suburb of Puerto Limón, Costa Rica. The strata exposed here correlate with the Moín [Moen] Formation of Gabb, 1895, which he referred to as post-Pliocene in age; Akers (1972, p. 42) states that the planktonic foraminiferal fauna in TU 954 is indicative of Neogene zone 22 of Blow, 1969, and hence of a basal Pleistocene age. An additional 214 valves have been collected at TU 1240 and 109 from TU 1307, both localities being at the top of a ridge that is approximately 60 meters higher in altitude than TU 954. Here the planktonic foraminifera indicate a middle Pleistocene age.

Gabb (1881), described the "Moen" fauna and referred to "a small plicate oyster in the deposit," which he questionably identified as *Ostrea borealis* Lamarck. It seems most probable that this identification was based upon representatives of the present species; particularly since our extensive Tulane University collections from Moín and the outskirts of Limón contain no plicated ostreid species.

DIMYA TIGRINA Bayer
Plate 4, figures 5-7

Dimya tigrina BAYER, 1971, Bull. Marine Sci., v. 21, no. 1, p. 223, figs. 69 (three views), 71A ["off Punta Piedras, Colombia: 9°45.1′N, 76°09.1′W, 79-75 meters"].

Bayer described this, the second Recent species of *Dimya* to have been reported from the western Atlantic area, as follows:

"Shell attached by the right valve, obliquely ovate, broader posteriorly. The hinge line is not auriculate, rather long, about 0.5 of the length of the mantle cavity (defined by the extreme limits of the pallial impression), straight, flat, transversely grooved, narrower and faintly impressed beneath the umbo. The thin, linear external ligament is visible along the whole hinge line; a deep, ovate pit beneath the umbos, closer to the posterior than to the anterior, accommodates the internal ligament. Exterior of left valve dull, pale brown marked with narrow, irregular radial streaks of darker brown; umbonal and central area externally smooth, marginal area sculptured by low, irregular radial ribs and thin, slightly raised concentric growth lamellae, resulting in a delicately scaly or frilly surface showing only faint traces of nacreous iridescence; interior of left valve porcellaneous, transluscent, allowing the nacreous layer to show through marginally and showing distinct radial streaks of reddish brown; surface glossy marginally but within the pallial line dull except for the glossy muscular impressions.

"Interior of attached valve cream white with conspicuous pattern of irregular radial streaks and spots of reddish brown most intense at the margins; surface marginally glossy, centrally dull except for the glossy muscular impressions; a wide band of irregular, narrow radial grooves and wrinkles lies within the pallial line, narrowing toward the hinge where the wrinkles break

up into granulations that merge with the cross-striated hinge line.

"Anterior muscular impression elliptical, near the end of the hinge line and closer to the umbo than is the posterior impression. Posterior muscular impression well removed from the end of the hinge line, distinctly double, that in the left valve more clearly bilobed than that in the right.

"The wide margin of the right valve is free of the substrate and flares broadly; its outer surface is marked with low, broad radials crossed with scaly concentrics resulting in an imbricated appearance.

"*Measurements* — Left valve, length 9.4 mm, height at umbo, 7.85 mm, right valve, length 9.4 mm, height at umbo 8.0 (holotype)."

Although not explicitly so stated, it appears that this description was based upon the single, paired-valve, holotype specimen. The twelve specimens of this species from the early Pleistocene, Moín Formation, at Moín Hill and near Puerto Limón, Costa Rica, reveal variation in some of the characters, especially in the nature of the hinge line. In most it is relatively elongate as described, but in one or two it is short to almost non-existent, with the site of the internal ligament being more or less at the apex of an angulate dorsal margin. Furthermore, the position of the internal ligament pit relative to the hinge line varies a great deal, one specimen having it at the extreme posterior end, while in some others it is anterior to the mid-line, the position apparently being affected by the nature of the attachment area of the right valve.

The characteristic color pattern is, of course, absent from the fossil specimens, but other factors, including the size, nature and position of the muscle scars, and the external ornament (compare pl. 4, figs. 5a, b, 7, with fig. 69 of Bayer, upper left and lower views) leave little doubt that these specimens represent the shallower water Recent species.

Six of the fossil specimens were collected at Tulane University locality TU 954 near Puerto Limón, Costa Rica, and six are from TU 953, in the railroad cut at Moín Hill, type locality for the Moín Formation of Gabb, 1895.

Figured specimen, USNM 263989; height 5.7 mm, length 6.6 mm, a left valve; locality TU 953. (Plate 4, fig. 7)

Figured specimen, USNM 263988; height 6.3 mm, length (incomplete) 6.3 mm, a right valve; locality TU 953. (Plate 4, fig. 6)

Figured specimen, USNM 263987; height 4.4 mm, length 5.2 mm, a right valve; locality TU 953. (Plate 4, fig. 5)

DIMYA species
Plate 1, figure 10

Three right valves of another species of *Dimya* are in the Tulane University collections from the well-known fossil locality at Bowden, Jamaica. Two are attached to a left valve of *Scapharca halidonta* Dall; one of these is very small and immature, the other (here figured), although attaining a height of 8.7 mm, and a length of 10.2 mm, is yet too thin and appressed to the irregular surface of the arcid valve to permit any observations of the positions of the adductor scars or other features that might serve to permit specific identification. The third specimen is fragmentary, having lost most of the dorsal area when broken free from the attachment surface, which is still present over most of the exterior of the valve; the small area exterior to this is marked by numerous exceedingly fine, hair-like radial riblets. These are rather similar to the fine radials that ornament the more coarse costae in *D. grandis divaricata* and, to a lesser extent, some specimens of *D. fimbricostata,* n. sp., but there is no suggestion indicative of the presence of stronger primary ribbing on the Bowden specimens.

Figured specimen, USNM 263968; height 8.7 mm, length 10.2 mm; locality TU 705.

APPENDIX I: SPECIES REFERRED TO THE GENUS *DIMYA*

The following list includes those species known to the writer that have been, at one time or another, referred to the genus *Dimya,* either by their authors or by subsequent students.

argentea DALL, 1886, Bull. Harvard Mus. Comp. Zool., v. 12, no. 6, p. 228, pl. 4, figs. 5a, b. Recent, western Atlantic Ocean.

bonneti COSSMANN, 1902, Ann. Soc. Roy. Malac. Belgique, v. 36, p. 21, pl. 2, figs. 14, 15. Lutetian (middle Eocene), Saulxmarchais, France.

californica BERRY, 1936, Proc. Malac. Soc. London, v. 22, no. 3, p. 126, pl. 13B, figs. 1-4. Recent, off Southern California.

checchiai SERRA, 1936, Bol. Soc. Geol. Ital., v. 55, no. 1, p. 125, pl. 3, figs. 7, 7a. Maestrichtian (Upper Cretaceous), Tripolitania, [Libya]. [?= *Dimyopsis*].

coralliotis BERRY, 1944, Proc. Malac. Soc. London, v. 26, no. 1, p. 25, figs. 1-4. Recent, off Southern California.

corugata HEDLEY, 1902, Mem. Australian Mus., v. 4, p. 308, text fig. 52. Recent, off New South Wales, Australia. (Type of *Dimyarina* Iredale, 1936).

crearoi OPPENHEIM, 1900, Palaeontographica, v. 47, p. 127, pl. 3, figs. 15-19. Priabonian (upper Eocene), north Italy.

deshayesiana ROUAULT, 1850, Mém. Soc. Géol. France, (ser. 2) v. 3, pt. 2, p. 471, pl. 15, figs. 3, 3a, 3b. Middle Eocene, Bos d'Arros, near Pau, southwestern France. Type of genus.

dissimilis TATE, 1886, Trans. Roy. Soc. South Australia, v. 8, p. 100, pl. 8, figs. 9a, b. Miocene, South Australia. [Figured as *Dimyodon dissimilis* by Bittner, 1895, pl. 23, figs. 33-37 (10 views)].

extenuiplicata SACCO, 1897, I Molluschi del terreni terziarii del Piemonte e della Liguria, pt. 23, Pelecypoda (Ostreidae, Anomiidae e Dimyidae), p. 42, new name for *Ostrea tenuiplicata* Seguenza, 1879, p. 123, pl. 12, fig. 1. Aquitanian (lower Miocene) to Astian (lower Pliocene), Calabria, southern Italy.

filipina BARTSCH, 1913, Proc. U.S. Natl. Mus., v. 45, no. 1983, p. 305, pl. 28, figs. 1-4. Recent, off Amina Sola Isl., Philippines.

fragilis VON KOENEN, 1893, Abh. Geolog. Specialkarte v. Preussen u. Thuringischen Staat., v. 10, pt. 5, p. 1065, pl. 69, figs. 5a-c, 6a-c. Lattorfian (lower Oligocene), northern German.

fragilis crassiplicata SACCO, 1897, *supra,* p. 42. Tortonian (upper Miocene), northwestern Italy.

fragilis miopliocenica SACCO, 1897, *supra,* p. 41, pl. 11, figs. 41-57. Helvetian (middle Miocene) to Plaisancian (lower Pliocene), northwestern Italy.

fragilis punctata NOSZKY, 1939, Ann. Hist. Nat. Mus. Hungary, v. 32, (Min., Geol. & Paleont.), p. 87 [as *"Dymia "*]. Rupelian (middle Oligocene), Hungary.

grandis DALL *in* GUPPY and DALL, 1896, Proc. U.S. Natl. Mus., v. 19, no. 1110, p. 328; DALL 1898, Trans. Wagner Free Inst. Sci., v. 3, pt. 4, pl. 35, fig. 8. "Oligocene" [= upper Miocene], Dominican Republic.

grandis divaricata DALL *in* GUPPY and DALL, 1896, *ibid.*, p. 338. Occurs with *grandis s. s.*, Dominican Republic.

internostriatum "Gumbel" FRAUSCHER, 1886, Denkschr. k. Akad. Wiss., Wien, Math. Naturw. Kl., v. 51, p. 36, pl. 3, figs. 11a-d, 12 [*as Cyclostreon*]. Lower Eocene, northern Alps.

intustriata D'ARCHIAC, 1850, Mém. Soc. Géol. France, (ser. 2) v. 3, pt. 2, p. 441, pl. 13, figs. 9, 9a, 10, 10a, 11 [as *Anomia*]. Middle Eocene, southwestern France. [Many authors cite as *"intusstriata";* has been repoted from the lower and middle Eocene of France, Italy, Bavaria, Bulgaria, north Africa, the Crimea and Ukrainia.]

japonica HABE, 1971, Veliger, v. 13, no. 4, p. 331, figs. 9-19. Recent, Japan. Identified as *D. lima* Bartsch, by Habe in several publications, 1958-1965.

kaiparaensis LAWS, 1944, Trans. Proc. Roy. Soc. New Zealand, v. 73, no. 4, p. 300, pl. 45, fig. 26. Lower Miocene, New Zealand.

libyca QUAAS, 1902, Palaeontographica, v. 30, pt. 2, p. 180, pl. 21, figs. 3a-c. Upper Cretaceous, Libyan Desert. [Appears to be *Dimyopsis.*]

lima BARTSCH, 1913, Proc. U.S. Natl. Mus., v. 45, no. 1983, p. 306, pl. 27, 28, figs. 5, 6. Recent, Philippine Islands [reported from Arafura Sea by Prashad (1932, p. 118, pl. 3, figs. 21, 22)].

maoria POWELL, 1937, "Discovery" Repts., v. 15, p. 168, pl. 45, fig. 2 [as *Dimya (Dimyarina)*]. Recent, off Three Kings Islands, northwest of North Island, New Zealand.

mimula DALL, BARTSCH, and REHDER, 1938, Bernice P. Bishop Mus., Bull. 153, p. 78, pl. 19, figs. 1, 2. Recent, off south coast of Molokai, Hawaiian Islands.

molokaia DALL, BARTSCH, and REHDER, 1938, *ibid.*, p. 79, pl. 19, fig. 3. Recent, off north coast of Molokai, Hawaiian Islands.

obliqua SCHAFHAUTL, 1863, Süd-Bayerns Lethaea Geognostica, p. 135, pl. 45-c, fig. 9 [as *Anomia*]. Eocene, Bavaria [cited as synonym of *"Deuteromya intusstriata* (Archiac)" by Zelinskaya *et al.* (1968, p. 53)].

pamplonensis CAREZ, 1881, Etude terrains Cretaces et Tertiaires du nord de l'Espagne, p. 310, pl. 8, figs. 2-5 [as *Plicatula*]. ["appears to be a *Dimya" fide* Eames, 1951, p. 354.]

radiata KURODA, 1928, Venus, v. 1, p. 14, pl. 1, fig. 11. Recent, Japan.[Synonym of *D. filipina* Bartsch, *fide* Habe, 1971, p. 330.]

radiata takii KURODA, 1933, Venus, v. 3, no. 3, App., p. 11, pl. 53, fig. 1. Recent, Japan. [Synonym of *D. filipina* Bartsch, *fide* Habe, 1971, p. 330.]

raulini COSSMANN and PEYROT, 1914, Conch. Néogénique de l'Aquitaine, v. 2, pt. 2, p. 409, pl. 22, figs. 12-15. Helvetian ?, southwestern France [see p. 36].

richei DONCIEUX, 1911, Ann. Univ. Lyon, (n. s. 1) v. 30, p. 34, pl. 6, figs. 7a, b. Oligocene, southern France.

sigillata TATE, 1886, Trans. Roy. Soc. South Australia, v. 8, p. 100, pl. 8, figs. 8a, b. Upper Eocene, South Australia.

spondyliformis EAMES, 1951, Philos. Trans.

Roy. Soc., v. 235B (627), p. 354, pl. 12, figs. 51, 52a-d, 53 [as "*Dimya* ?"]. Eocene, western Punjab.

subrotunda FELIX, 1891, Palaeontographica, v. 37, p. 163, pl. 25, figs. 9, 9a. Neocomian (lower Cretaceous) Mexico [appears referable to *Dimyodon*, see p. 35].

tabasaranica (KOROBKOV, 19??), [original description not found; fig'd., as "*Deuteromya tabasaranica*" in Korobkov, 1954, Reference and Method. Guide to Tertiary Mollusca. Lamellibranchia, pl. 76, figs. 14-18, "upper Eocene, Kavkaz", Dagestana.]

tigrina BAYER, 1971, Bull. Marine Sci., v. 21, no. 1, p. 223, figs. 69 (3 views), 71A. Recent, Caribbean Sea.

westonensis MAXWELL, 1978, New Zealand Jour. Zool., v. 5, p. 15, figs. 1, 2. Upper Eocene, New Zealand.

sp. ? VINCENT, 1930, Mus. Roy. Hist. Nat. Belg., Mém. 46, p. 76, pl. 4, fig. 6 [as *Dimya* ? sp. ?"]. Paleocene, Poudingue de Ciply, Belgium.

sp. ? GLIBERT and VAN DE POEL, 1973, Inst. Roy. Sci. Nat. Belg., Mém. 175, p. 16 [as "*Dimya* sp ?"]. Paleocene, Calcaire de Mons, Belgium.

APPENDIX II: SPECIES REFERRED TO THE GENUS *DIMYODON*

boehmi STOLLEY, 1892, Mittheil. Min. Inst. Univ. Keil. v. 1, no. 7, p. 243, pl. 2, fig. 8 [as "*Böhmi*"]. Upper Cretaceous, Schleswig-Holstein, northwestern Germany; also reported from Denmark (Grönwall, 1900, p. 78) and the "Upper Chalk" of England (Grönwall, 1906, p. 203).

costatus GRÖNWALL, 1900, Meddel. Dansk. Geol. Forening, v. 1, no. 6, p. 77, pl. 2, figs. 4-7. Upper Cretaceous, Denmark, France.

dissimilis TATE, 1886 [see listing under genus *Dimya*].

intusradiatum "Gumbel" BÖHM 1891-92, Paleontographica, v. 38, p. 88, pl. 4, figs. 2a-e. Upper Cretaceous.

nilssoni HAGENOW, 1842, Neues Jahrb. für Min., p. 546 [as "*Ostrea*"]. Upper Cretaceous. Reported by several writers from Germany, Denmark, Holland, France, and England. Trechmann (1935, p. 173) has cited it as possibly occurring ["cf."] in the Northern Range of Trinidad, the sole western Atlantic record.

plicatuloides "Leym." COQUAND, 1869, Mon. du genre *Ostrea*, p. 194 [as *Plicatula*]. [NOT *Ostrea plicatuloides* Leymerie, 1851, Mém. Soc. Géol. France, (ser. 2) v. 4, p. 195, pl. 9, figs. a-c; *fide* Grönwall, 1900, p. 74, and 79-80.]

richthofeni BITTNER, 1895, Abh. k. k. geol. Reichsanst., Wien, v. 18, pt. 1, p. 217, pl. 23, fig. 32 (3 views). Upper Triassic, St. Cassian, northeastern Italy.

schlumbergeri "Munier-Chalmas" FISCHER, 1886, Man. de Conchyl. et de paléont. Conchyl., p. 936, text fig. 705. Bathonian, Jurassic, France. Type of genus.

sigillina WOODWARD, 1864, Geol. Mag., v. 1, p. 112, pl. 5, figs. 1-5 [as "*Plicatula*"]. Upper Cretaceous, England. Referred to *Dimyodon* by Woods, 1903, p. 225.

similis VON KOENEN, 1893, Abh. Geolog. Specialkarte v. Preussen u. Thuringischen Staat., v. 10, pt. 5, p. 1067, pl. 69, figs. 8a-c. Lattorfian (lower Oligocene), Germany and Ukraine (Sokolow, 1905, p. 48, pl. 12, figs. 14-16, pl. 13, fig. 3).

similis interstricta NOSZKY, 1939, Ann. Hist. Nat. Mus. Hungary, v. 32, p. 34. Rupelian (middle Oligocene), Hungary.

storrsi SMITH, 1927, U.S. Geol. Surv., Prof. Paper 141, p. 122, pl. 96, fig. 1. Upper Triassic, California [?, a *Dimyopsis*, see p. 35].

woehrmanni BITTNER, 1895, Abh. k. k. geol. Reichsanst., Wien, v. 18, pt. 1, p. 219 [as "*wöhrmanni*"], new name for "*Dimyodon intusstriatus* Emmr. spec. bei Baron Wöhrmann, Jahrb. d. geol. Reichsanstalt 1889, S. 209, Tab. VIII, Fig. 4, 5, 6 (excl. synon.!)". "Carditaschichten", Upper Triassic, Tyrol.

VII. LOCALITY DATA

The following are Tulane University fossil collecting localities:

226. Red Bluff Clay, east bank Chickasawhay River, about one mile south of Hiwanee, 3.5 miles south of Shubuta (SW ¼ Sec. 28, T10N, R7W), Wayne Co., Mississippi.

642. Red Bluff Clay, east bank Chickasawhay River, bluff immediately west of Hiwanee (NE ¼ Sec. 28, T10N, R7W), Wayne Co., Mississippi.

705. Bowden Formation, roadcut at Bowden, east of Port Morant, Parish of St. Thomas, Jamaica.

953. Moín Formation, railroad cut and adjacent ditches on east side of road from Moín Junction to Sandoval, 4.5 km west of Puerto Limón, Costa Rica. [At Moín Hill, type locality of Moín Formation.]

954. Moín Formation, hill cut immediately behind the Standard Fruit Company's box factory, just west of cemetery at Pueblo Nuevo, about 2 km west of Puerto Limón, Costa Rica.

1209. Gurabo Formation, road cuts on both sides of Los Quemados — Sabaneta Road 2 kms west of Los Quemados and 0.6 km east of the crossing of the Rio Gurabo, Dominican Republic.

1210. Gurabo Formation, Rio Gurabo, east

bank, first bluff downstream from bridge on Los Quemados — Sabaneta road, Dominican Republic [= USGS 8544; Maury's Zone "B"].

1211. Gurabo Formation, Rio Gurabo, west bank, second bluff downstream from bridge on Los Quemados — Sabaneta road, Dominican Republic [= USGS 8546].

1215. Gurabo Formation, Rio Gurabo, bluffs on both sides of river from bridge on Los Quemados — Sabaneta road to a point approximately 1 km upstream, Dominican Republic [= USGS 8539-8543; Maury's Zone "D"].

1219. Gurabo Formation, Rio Amina, bluffs on east side of river immediately upstream from ford that is 2 kms west of Potrero and about 3 kms downstream from "La Represa," Dominican Republic [= USGS 8516].

1225. Gurabo Formation, banks of large arroyo on west side of Rio Mao, upstream from Mao Adentro and downstream from Cercado de Mao; about 11 kms (by winding road) south of Mao, Dominican Republic.

1227. Gurabo Formation, deep arroyo that crosses under road to Jánico from Santiago de los Caballeros, 11 kms south of bridge over Rio Yaque del Norte at Santiago, Dominican Republic.

1227A. Gurabo Formation, turbidity flow lens (ca. 30″ long, 6″ thick) about two feet above base of outcrop at point approximately 75 feet downstream from highway bridge, Dominican Republic.

1240. Moín Formation, Barrio Los Corales, top of hill at end of road that passes Standard Fruit Company's box factory (see TU 954); locality is 1.8 kms north of main highway at Pueblo Nuevo, which is 2 kms west of Puerto Limón, Costa Rica.

1254. Gurabo Formation, roadcut at top of hill, 4 km west of Duarte Highway, on road to Presa Tabera ; approximately 15 km south of Santiago de los Caballeros, Dominican Republic.

1277. Gurabo Formation, Rio Gurabo, upstream from horse-trail into canyon about 2 kms (airline) upstream from bridge of Los Quemados-Sabaneta road (see Vaughan *et al.*, 1921, pl. 11), Dominican Republic.

1279. Gurabo Formation, or base of Mao Adentro Formation, cut on south side of Los Quemados-Sabaneta road 2.5 kms west of junction at Los Quemados and about 0.3 km east of bridge over Rio Gurabo, Dominican Republic.

1288. Red Bluff Clay, type locality, east bank Chickasawhay River, about 1.5 miles south of Shubuta (NE ¼ Sec. 16, T10N, R7W), Wayne Co., Mississippi.

1289. Red Bluff Clay, east bank Chickasawhay River, about ¾ mile south of Hiwanee (SW ¼ Sec. 28, T10N, R7W), Wayne Co., Mississippi.

1291. Red Bluff Clay, Sand Branch of "Carson Sand Creek," about 4 miles by country road east of Hiwanee, and about 100 yards downstream from road crossing (SE ¼ Sec. 24, T10N, R7W), Wayne Co., Mississippi.

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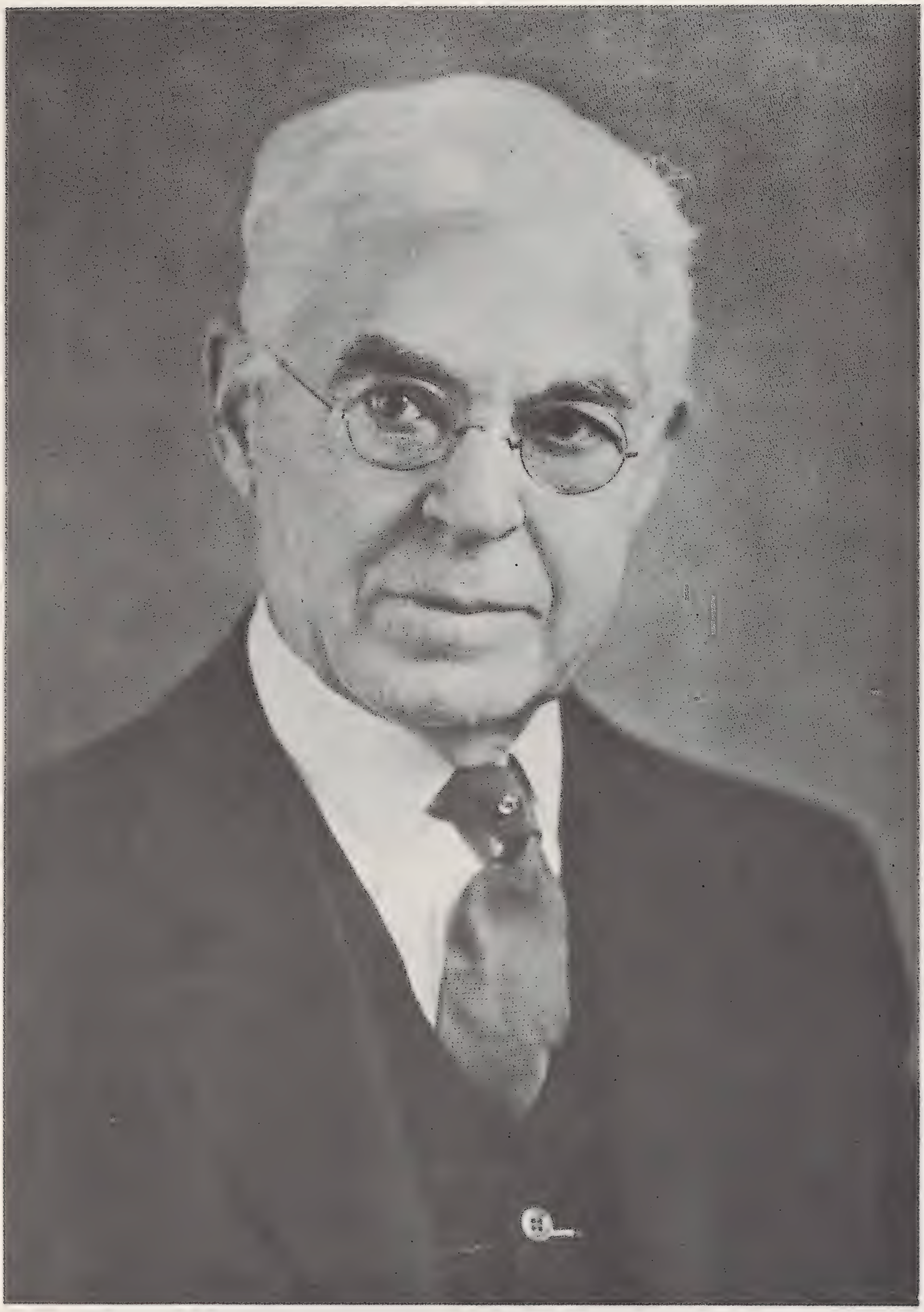
REVIEW

MESOZOIC PALYNOLOGY OF SVALBARD – I: The Rhaetian of Hopen, with a preliminary report on the Rhaetian and Jurassic of Kong Karls Land, by Tor Bjaerke and Svein B. Manum. Published by the Norsk Polarinstitutt, Oslo, 1977, 48 pp., 9 pls., $6.00 (distributed in the United States by the Columbia University Press, New York).

Palynomorphs from thirteen workable samples are described and illustrated, twelve are from shale-silt lithologies and one is a coal sample. The beds on Hopen (an island on the southeastern corner of the Svalbard archipelago) were regarded as Lower Cretaceous until the seventies when a series of reports on the contained plant macrofossils resulted in dating these beds as Rhaetian to lowermost Jurassic in age. A report by Smith (1974) supported this dating, but the present study yields results which restrict these beds to the Rhaetian. This work is very well illustrated with nine excellent plates.

—H.C.S.



GILBERT DENNISON HARRIS
(1864-1952)

EARLY GEOLOGISTS IN LOUISIANA

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INTRODUCTION

Louisiana was one of the first areas in America distant from the Atlantic Ocean to attract the attention of travellers and other observers who made geological commentaries on the regions they visited. The great Mississippi River and reports about the potential of the river for trade and access to the immense interior of North America formed the basis for this attraction. Before the year 1900, more than forty individuals did important geological work or made significant observations about the geology of the state of Louisiana. In 1899, Gilbert D Harris and Arthur C. Veatch reviewed the contributions of many of these observers in some detail. Among the early contributors, the work of five men can be considered to be major in its significance to the knowledge of Louisiana geology. These are, in chronological order, John L. Riddell, Sir Charles Lyell, Raymond Thomassy, Eugene W. Hilgard, and Gilbert D. Harris.

EARLY OBSERVERS (1726-1832)

The following list is based largely on the review by Harris and Veatch (1899, pp. 11-44) with additions and emendations from various other secondary sources and primary works. Among the subjects of great interest to travellers were the bluffs at Port Hudson, the Five Islands, the Mud Lumps, fossil bones, marine shells, iron ores, salt springs, and the age and origin of the delta.

1722 — Pierre François Xavier de Charlevoix commented on the recent age of formation of the lower delta region based on "the quantity of shoals and little islands that have been seen to form in the various mouths of the river during the past twenty years".

1726 — Daniel Coxe mentioned "many springs, pitts, and lakes which afford most excellent common salt in great plenty" along the "River *Natchitock*" (some ten or twelve leagues up the Mississippi), which the local Indians used as the source of salt for trade with their neighbors.

1773 — William Bartram, the renowned naturalist, entered and crossed Lake Pontchartrain to the river, which he ascended for some distance above the site of Baton Rouge. He described the varicolored strata in the bluffs at Port Hudson and the plains nearby of "whitish clay or chalk, with veins of sea-shells, chiefly of those little clams called les coquelles *[Rangia cuneata]* interspersed with the white earth or clay, so tenaceous and hard as to render it quite sterile." He speculated about the origin of the cypress stump horizon more than one hundred feet below the edge of the bluffs and how it came to be so deeply buried.

1801, 1803 — William Dunbar of Natchez, Mississippi Territory, communicated reports of fossil bones found west of the Mississippi River in 1801, and again, in 1803, of supposed elephant bones from the "country of the Apelousas." He also reported on the occurrence of oyster shells at depths of 22 feet below the present surface.

1812 — Amos Stoddard, in his *Sketches, Historical and Descriptive of Louisiana,* made several important geological observations. On the Mississippi Delta, he wrote "Nothing is more certain than that the delta has gradually risen out of the sea, or rather that it has been formed by alluvion substances, precipitated by the water from the upper regions. It is calculated that from 1720 to 1800, a period of eighty years, the land has advanced fifteen miles into the sea; and there are those who assert, that it has advanced three miles within the memory of middle aged men." On the Five Islands, Major Stoddard stated "There is an island of about three miles in circumference, situated in the gulf a few miles to the westward of the mouth of the Chafalia, elevated more than two hundred feet above the level of the sea and connected with the mainland by a sea marsh. Most of the islands along the shores of the Mexican gulf exhibit this proud pre-eminence, while the country for a great depth is most of the time covered with water. Some of

them are impregnated with sulphur, and one of them has been known to be on fire for at least three months." Stoddard reported the production of rock salt from saline springs near Natchitoches as about "two hundred and forty barrels of salt per month," and on the cause of the rapids at Alexandria as "two ledges of hard indurated clay, or soft rock which extend across the channel at about three-fourths of a mile from each other," and that "Stone or pit-coal is an article of some importance..." near Natchitoches.

1816, 1818 — William Darby was another perceptive traveller who included geological facts and occurrences within the text of his two travel narratives. He described fully the river systems in the Louisiana area and the terraces or "prairies" in the southwestern region. He visited Petite Anse (now Avery Island) and reported on the salt spring from which salt has been recovered. Darby observed rock exposures on the western side of Sicily Island and correlated them (quite correctly) with similar exposures on the Red River at Alexandria. He noted dead cypress trees in Lake Bistineau and ascribed the origin of this and similar isolated lakes to the "choking up" of smaller stream valleys by the sediments of the Red River. Darby found marine shells in the banks of the Red River, probably at the locality now known as Montgomery Landing.

1821 — Thomas Nuttall compared the ferruginous conglomerates extending for "more than a thousand miles above Alexandria" with the New Jersey conglomerate (later erroneously interpreted as Cretaceous in age by Morton).

1824 — George Graham, in his reports from the general land office for 1824, gave the locations of two salt springs to the north of the Red River.

1829 — Richard Delafield described the topography and the life history of the Mud Lumps in the Passes of the Mississippi.

DEVELOPMENTAL PERIOD (1832-1867)

1832 — Richard Harlan published the first formal, systematic paper on the geology of Louisiana, *Notice of Fossil Bones found in the Tertiary Formation of the State of Louisiana.* This report described the bones of a "huge lizard-like reptile" for which Harlan proposed the name *Basilosaurus*. The locality, in Ouachita Parish, lies about two hundred yards from the Ouachita River and the bones were exposed some forty feet below the present surface "embedded in a bank of sea marl". In addition, the nearby hills were reported as not composed of "rocks", but "a few sandy stones and pebbles, nearly all *siliceous,* are occasionally seen scattered on their summits or in the beds of the numerous creeks fed by springs issuing from them." Further, he observed "Sea shells . . . in several places . . . among others, *pectenites, belemnites,* etc." and that "In these hills very few ores are found except those of iron, which are abundant in two different places; but no measures have been taken to ascertain their value."

1833 — Samuel G. Morton concluded that the "ferruginous sand formation" (reported by Nuttall) and the fossil *Basilosaurus* bones (of Harlan's report) should be assigned to the "Cretaceous Group of the United States."

1834 — Timothy A. Conrad studied the shells found in association with the *Basilosaurus* and referred them to the "Eocene series" and stated that the "commonest fossil is *Corbula oniscus,* a common Claiborne fossil." He suggested that the fossil bones were from a nearby "Cretaceous stratum, not from the Eocene". Later, in 1841, Conrad described additional species of Eocene mollusks from the *Basiolsaurus* locality.

1838 — M. Deméril recognized the vertebrae known as *Basilosaurus* to be from a cetacean rather than a reptile.

1838, 1839 — William M. Carpenter communicated to the American Journal of Science discoveries of fossil vertebrate remains at two localities in southern Louisiana. *Equus* teeth and fragments of the jaw of a mastodon were found on Little Bayou Sara in West Feliciana Parish and additional mastodon bones were found near Opelousas. Also, he re-described the Port Hudson section and traced it eastward in the Florida parishes.

1839-1841 — John L. Riddell worked extensively on the geology of Texas and Louisiana, organized the Geological Committee of the State of Louisiana, and forwarded the results of the Louisiana surveys to the State Printer but these became lost before publication and no trace of this work

is known to have survived. (see full account of Riddell's work below)

1839 — Richard Owen [English] examined new and better preserved specimens of *Basilosaurus* vertebrae which had been brought to him in London by Dr. Richard Harlan and pronounced them the remains of "an aquatic mammal of dugong, or whale-like affinities." In 1841, Owen renamed the species *Zeuglodon cetoides*.

1839 — Captain Andrew Talcott (*in* Totten, 1840) made an accurate map of the mouths of the Mississippi River and prepared drawings of two of the Mud Lumps for a War Department publication.

1841 — A. C. Jones, an engineer, published a careful description of the physical nature of and character of the Mud Lumps in the lower passes of the Mississippi River.

1846 — Sir Charles Lyell visited America for the second time, came to the South, reached Mobile and travelled on through the waters of Mississippi Sound to Lake Pontchartrain and the city of New Orleans. As he went downriver to the mouths of the Mississippi and upriver to Port Hudson and beyond, he made numerous cogent observations about the local geology and the hydrodynamics of the river and its depositional activity. (see full account below)

1848 — Montroville W. Dickeson read a joint paper (with Andrew Brown) before the first meeting of the American Association for the Advancement of Science at Philadelphia. In this paper, *The Sediment of the Mississippi River,* Dr. Dickeson stated that the delta of the Mississippi River has been in the process of forming for at least 14,204 years.

1850 — Daniel Drake gave a good description of the Mud Lumps and proposed the gas theory for their origin within the pages of his medical work *A Systematic Treatise, Historical, Etiological, and Practical, on the Principal Diseases of the Interior Valley of North America, as they appear in the Caucasian, African, Indian and Esquimaux varieties of its population.* In this excellent example of how significant geological work can be concealed in unlikely places, Dr. Drake included a geologic section from a well on Lake Pontchartrain and the exposed section from a gas tank excavation at New Orleans. Further, he described the geological formations at Fort Jessup and stated that their age is Tertiary.

1853 — Charles Ellet, another civil engineer, prepared an extensive work containing plans for flood control and improved navigation on the Ohio and Mississippi rivers. An appendix dealt with the bars present in the passes in the lower delta area. Later in the same year, A. C. Jones published a severely critical review of this book.

1860 — Raymond Thomassy's *Géologie Pratigue de la Louisiane,* the first comprehensive attempt to describe the geology of Louisiana was issued (by the author) in New Orleans and Paris, in 1860. Thomassy, an hydraulic engineer, was concerned mainly with the rôle of the Mississippi River in the geological formation of the lower delta region. In particular, he emphasized water absorption and "diminution of volume" gulfward and "volcanic forces" in the origin of the Mud Lumps and the Five Islands which he recognied to be salt intrusions. (see full account below)

1861 — Andrew A. Humphreys and Henry L. Abbott completed their study of the hydrography and geology of the entire Mississippi Basin. They considered the river alluviums to be a thin stratum of river deposits underlain by blue clays of Tertiary or Cretaceous age. The older clays were recognized in the bluffs at Vicksburg, in the Yazoo river valley, and at a depth of about forty feet under the city of New Orleans. Their extensive work was revised and reissued in 1876. In the later edition, the "original mouth" of the Mississippi River was stated to be "near the efflux of the Plaquemine, 220 miles from the Gulf." The yearly advance of the passes of the river was computed at 262 feet, with the advance from the Plaquemine efflux estimated to have taken 4400 years.

1864 — An effort toward a general survey of the geology of Louisiana and its mineral resources began early in 1864 with the appointment by Governor Henry W. Allen of a commission headed by John B. Robertson of New Orleans to begin a systematic investigation of the agricultural, geological, and mineral resources of the state. George P. Merrill (1920, p. 124) in his history of American state geological and natural history surveys stated quite erro-

neously that this was "the first step taken by State authority toward a general survey". The Riddell survey of 1839-1841 was actually the first such "step" authorized by the state and paid for by state funds. Judge Robertson was assisted in his studies by Charles Tripp, mineralogist and metallurgist; John H. Jones, skilled ironmaster; and, Captain John Roy, practical machinist and artisan. The report of the Robertson Survey comprising 25 octavo pages was published in the legislative reports for 1867. The surface geology in central and northern Louisiana was described in very general and simple terms, including mention of "vast hills, sometimes over 200 feet in height . . . unheaved by volcanic action . . . and covered with fragments of red sandstone formerly stratified." This last reference evidently is to the characteristic ferruginous sandstones which had been reported by several earlier observers. The Five Islands were described and were stated to be of volcanic origin. The rock salt of Petite Anse (Avery Island) was noted and compared with the "salines of north Louisiana and their deposits of bones." The iron region of northern Louisiana was reported as quite extensive, and was said to be "so abundant as absolutely at some points to obstruct agriculture." Also, "Vast crops of rich ores may be seen piled up in the fields." Various other mineral deposits were mentioned including lead, copper, limestones, clays, ochres, gypsum and soda springs, lignite, peat, and petroleum.

1865 — Richard Owen [American], then colonel of an Indiana regiment stationed at New Iberia, briefly examined the geological nature of Petite Anse and the deposits of rock salt which had been mined since the early days of the war. Prof. Owen concluded that these islands were not of volcanic origin, but were wind and wave-formed dunes like those along the southern shore of Lake Michigan. The salt beds he attributed to the result of the evaporation of sea water in lagoons behind the protecting ridges or dunes, which were filled and refilled during periods of exceptionally high tides.

RECONNAISSANCE PERIOD (1867-1892)

1867 — Eugene W. Hilgard, working for the Smithsonian Institution, came to Louisiana, travelled down the Mississippi, and made an excursion to the intermediate three of the Five Islands, (Petite Anse or Avery Island, Weeks Island, and Côte Blanche Island). In his preliminary report which appeared in 1869 he attributed the rock salt to being formed by evaporation in a series of lagoons, considered it underlain by early Quaternary marine clays, and explained the hills as accidents of differential erosion. In another work published in the same year he reviewed the geology of western, central and northern Louisiana. Hilgard continued to write on the geology of Louisiana for nearly twenty years. (see full account below)

1869 — Frederick V. Hopkins began his work on the Louisiana survey with three geological excursions during 1869 in northern Louisiana and completed his "first annual report" later in the same year. He described the known geological formations from the Cretaceous to the recent or alluvial formations and included a simple cross-section illustrating his views of the stratigraphic position of the strata and the structure of the area. Hopkins commented on the subsurface section in wells connected with various salt-works and gave a section in detail from the sulphur well at Calcasieu (see Harris and Veatch, p. 33). He suggested that "The sulphur was formed by reducing the gypsum with vegetable matter. The carbonic acid, olefiant gas and the marsh gas produced by the process, have each left the proof of its presence, *i. e.*, the limestone stratum No. 5 contains the former, the petroleum is made from the olefiant gas" and the "small low mounds of that and other regions were formed by the escaping of these gases." He described the lithology, paleontology, and distribution of the "Mansfield group," the "Jackson group," the "Vicksburg formation," the "Grand Gulf group," and the "Drift Period." All of these geologic units had been included in Hilgard's geologic sections. The *Second Annual Report of the Geological Survey of Louisiana* was completed in 1870 and published the following year, accompanied by the first geological map of the state; it is colored. He correlated the "Mansfield group" with marine Jackson beds, and included long lists of Jackson and Vicksburg fossils. The second report is merely a corrected and augmented revision of the first report, to which was added the colored geological map. The

third *Annual Report* is devoted principally to the "Drift" and the alluvium which he traces in terms of its depth and character through much of southern Louisiana. He recorded loess 150 feet thick in the Tunica Hills and included a long list of Paleozoic fossils found in the pebbles of the "drift gravels" which he regarded as Quaternary in age and formed by "an arctic current flowing from Hudson bay."

1870 — Arthur M. Edwards in *Results of a Microscopical Examination of Specimens of Sand obtained from an Artesian Well at New Orleans* reported a gas bearing light grayish sand with fine specks of organic material at 32 feet, clear transparent quartz sand with black organic specks and a "few comminuted mollusks" at 49 feet, and fine sea-bottom deposits with many sea-shells at 71 feet. Edwards recorded *Diatomaceae* of the same species now found living off the coasts of Florida and South Carolina.

1874 — S. Dana Hayes made an analysis of lignite taken from a deposit two miles south of Shreveport, reporting that it "has a specific gravity of 1.143, it is nearly black in color, and its lignitic structure is not so distinct as usual; but it dissolves comletely in caustic soda solution."

1875 — Caleb G. Forshey in his *Report of Survey and Borings made at the Proposed Site of the Lake Borgne Outlet* based on 14 "soundings" to depths of 70 to 100 feet noted marine shells belonging to species now living in Florida waters and reported violent eruptions from depths of 60 to 70 feet of shells and mud with hydrogen gas which "burns with a reddish flame." He compared this with phenomena observed at the Mud Lumps.

1875 — William M. Gabb stated that the Gulf of Mexico was more open in Miocene time than it is today based on his study of the marine Miocene deposits in the West Indies and in Costa Rica.

1884, 1889 — Joseph Leidy published a short report in 1884 on fossil bones from Petite Anse, followed by a longer more detailed report in 1889. He listed *Mastodon americanus, Mylodon harlani* (?), and *Equus major* among the species from Petite Anse.

1885, 1886 and *1891* — Lawrence C. Johnson surveyed the iron ores of Louisiana and northeastern Texas for the United States Geological Survey (published 1888). A map was prepared showing the distribution of the ores and he included drawings to illustrate some exposures. Johnson's stratigraphy follows Hilgard's interpretations, but he found several new localities for fossils and his extensive collections were placed in the United States National Museum. Truman H. Aldrich studied the mollusks and was enabled to correct some previous correlations. In 1891, Johnson published a brief report on *The Nita Crevasse* in which he stated that the Pontchartrain clays (which he correlated with the Port Hudson beds) were deposited during a former period when the Mississippi River debouched through Manchac.

1888 — Frank H. Knowlton described two species of fossil palm wood, *Palmoxylon quenstedti* and *Palmoxylon cellulosum*, from Rapides Parish which had been collected by Johnson in 1886. Later, Knowlton described more fossil wood from other Louisiana localities.

LOUISIANA EXPERIMENT STATIONS (1892-1899)

1892, 1893 — Dr. Otto Lerch worked on the geology of Northern Louisiana during the early part of 1892. Later in the year, he published *A Preliminary Report upon the Hills of Louisiana, North of Vicksburg, Shreveport and Pacific Railroad*, a work of 52 pages with text-figures largely concerned with the description of localities along the route of the railroad. He provided an account of Rayburn's Salt Works, including the stratigraphy of the area and was the first observer to report Cretaceous fossils from this locality. Seven analyses of artesian wells and spring-waters, ten soil analyses, tests on three specimens of iron ore and two samples of lignite, and a list of fossils from the Green Sand Marl northeast of Mount Lebanon were included. Lerch continued with field work during the summer months of 1892, and in 1893 his *A Preliminary Report upon the Hills of Louisiana, South of the Vicksburg, Shreveport and Pacific Railroad* appeared, dealing with the topography, drainage and lakes of the area, followed by the various formations exposed in this portion of the state from the known Cretaceous outcrops at Drake's Salt Works and other localities through the overlying Tertiary beds exposed in this region. These include the

"lower Eocene beds" or the "lower lignitic," the "marine Claiborne" or "upper lignitic" beds, the "Arcadia Clays," the "Jackson beds," the "Vicksburg," the "Grand Gulf," the Red Sandy Clays," the "Sands and Gravel of the Drift," and finally, the "Alluvium." Among the economic materials discussed are the Winnfield "Marble," various building stones, gravels, iron, clay, kaolin, salt, and lignite with analyses of 45 soil samples, ten marls, and four lignites. To explain the northwest-southeast trend of the outcrops, Lerch concluded "that at the close of the Mesozoic time enormous plutonic forces convulsed, fractured, faulted and folded the Cretaceous strata, throwing up mountain chains of vast extent and raising them far above the waters of the Gulf."

1894 — Gilbert D. Harris made a brief visit to Bossier and Claiborne parishes during his work on the Tertiary deposits of southern Arkansas to determine what could be gained from the fossiliferous deposits of Louisiana to assist in classifying equivalent strata in Arkansas. His observations and results were published (1894) in the *Arkansas Geological Survey Annual Report for 1892*. This represents the first involvement of Gilbert D. Harris in the geology of Louisiana.

1895 — Edward D. Cope published notes "On Some Pleistocene Mammalia from Petite Anse, La." Therein, he reported two new species of *Mylodon* and one of *Equus*.

1895, 1896 — T. Wayland Vaughan published *The Stratigraphy of Northwestern Louisiana* based on field work between 1889 and late 1894. Vaughan treated the stratigraphy chronologically beginning with the Cretaceous and continuing through the Jackson, Claiborne (to which he referred Lerch's "Arcadia Clays"), Vicksburg, and Grand Gulf beds. New units described include the "Cocksfield Ferry beds" and the "Sparta Sands." Vaughan opposed Lerch's structural disturbance at the "close of the Cretaceous deposition" and proposed in its place a period of erosion between the Cretaceous and the Eocene strata. in 1896, Vaughan published an expanded version of this work with a bibliography and lists and descriptions of fossils as *United States Geological Survey, Bulletin* 142.

1896 — William W. Clendenin continued the work for the Experiment Stations in 1894 and 1895 with investigations in the "Florida Parishes of East Louisiana" and the "Bluff, Prairie and Hill Lands of Southern Louisiana." His reports on the general topographical features of these areas appeared in 1896. He considered the "Five Islands" to have been uplifted subsequent to the deposition of the Lafayette gravels, rather that the product of pre-Tertiary erosion as suggested by Hilgard. He included several well sections from southern Louisiana in his reports and wrote a general account of the life history and development of a river and related this to the Mississippi River and its development.

1899 — Charles W. Johnson published *New and Interesting species in the "Isaac Lea Collection of Eocene Mollusca"* listing and describing species from the Jackson and lower Claiborne beds in Louisiana.

1898, 1899 — Gilbert D. Harris, assisted by Arthur C. Veatch and others began working on the geology of Louisiana. Harris was appointed as Geologist-in-charge to the Geological Survey of Louisiana and continued in this position until 1909. With Gilbert D. Harris, the early formative stages of Louisiana geological work ended and the modern period of study began. (see full account below)

JOHN L. RIDDELL

Though the primary interests of John Leonard Riddell (1807-1865) were directed toward the other sciences, notably chemistry and botany, and to the field of medicine, his geological contributions were considerable. Riddell's importance to the development of geology in the midwest and the south has been overlooked by historians. For the complete historical treatment of Riddell, his life, and his multifaceted accomplishments see John Leonard Riddell by Karlem Riess (1977), which is a principal source for much of the present narrative.

John L. Riddell's early education was in Massachusetts and New York. From 1827 to 1829 he attended Rensselaer School in Troy, New York, where he studied under Amos Eaton, the celebrated first American teacher of geology. Riddell received his Bachelor of Arts degree in 1829, and sev-

eral years later (1832) was awarded the Master of Arts degree (in absentia). Riddell's first scientific lecture, *A New Theory of the Earth,* was delivered at Rensselaer School on August 16, 1829, and dealt with the various geological formations on Earth and the types of fossil remains found with these formations (Riess, 1977, p. 5-6).

Between 1830 and 1832, John L. Riddell travelled extensively in New York, Ontario, Pennsylvania, and Ohio, presenting public lectures on chemistry, physics, and botany, supported by subscription fees. Late in 1832, he was appointed professor of chemistry and botany at the Ohio Reformed Medical College, Worthington, Ohio. During his two years at Worthington, he began studying the geology of the state, and in 1833, *Geology of Ohio,* his first formal paper on geological subjects was published in the *Western Journal of the Medical and Physical Sciences*. In 1834, he moved to Cincinnati where he attended the Medical College of Ohio and was awarded the M. D. degree in 1836. During 1835 and 1836, he completed several other geological articles, including *On the Vegetable Origin of Coal* (1835), *Geological Features of Ohio* (1836), and *Geological Ramble on the Western Reserve* (1837). In 1836, Riddell married for the first time, and worked on a *Survey of the Geology of Ohio* under Dr. Samuel P. Hildreth. Riddell's portion of this report was submitted and published in 1837.

In October 1836, John L. Riddell and his wife moved to New Orleans where Dr. Riddell had been offered the professorship in chemistry at the New Orleans Medical College. He was destined to reside in this city until his death nearly thirty years later. In 1839, Riddell began his attempts to secure authorization by the State Legislature to conduct a geological survey. In mid-April to late May in the same year and again in mid-September to mid-November, he made geological excursions to Texas, in part to search for Spanish gold and silver mines. His Texas surveys were quite extensive, and one complete volume of Riddell's manuscript *Journal* is filled with his observations on Texas formations, flora, Mexican food, bits of history, and living conditions on these excursions (Riess, 1977, p. 31). *Observations on the Geology of Trinity Couty, Texas* was published in the *American Journal of Science and Arts* in 1839 with detailed descriptions of the soil, rocks, springs, and terrain of the region surveyed. He included analyses of waters from the mineral springs and commented on the brown coal or lignite deposits and their commercial possibilities as fuels — long before the time of Robert T. Hill!

Finally, in 1841, the Geological Committee of the State of Louisiana was appointed with Riddell as Chairman. The other committeemen were Dr. W. M. Carpenter, Dr. Thomas Ingalls, Dr. Josiah Hale, Caleb G. Forshey, and P. E. Trastour. The results of their work were turned over to the State Printer but, tragically, were lost before being published and no trace of the manuscript is known to exist today. The specimens collected by the Geological Committee were left with the Medical Department of the University of Louisiana.

In 1844, John L. Riddell was appointed to the State Flood Prevention Committee by the Governor of Louisiana. In 1845, *Deposits of the Mississippi and Changes at its Mouth* was read before the Association of American Geologists and Naturalists and later was published in DeBow's *Commercial Review* as *Sedimentary Deposits of the Mississippi*. Also, a pamphlet *Remarks on the Dynamics of the Mississippi River and other matters pertaining thereto* was printed and distributed in New Orleans. Riddell estimated that 119,250 years were required to create the Mississippi delta (Riess, 1977, p. 38).

In 1851, Riddell conceived of and designed the stereoscopic binocular microscope. He built the instrument and tested it in 1852, and on July 30, 1853, he described his invention before the American Association for the Advancement of Science. This without doubt is the most significant of his scientific or technological achievements. John L. Riddell was one of the founders of the New Orleans Academy of Sciences in 1853, and in 1855, he was elected President of the Academy which honor he retained until his death in 1865. In 1855, the New Orleans Academy of Science revived the Geological Survey project, but as the State Legislature failed to support the project with enthusiasm, the survey was never completed.

SIR CHARLES LYELL

In 1845-1846, Charles Lyell (1797-1875), renowned British geologist, made a sec-

ond visit to the United States of America, a geological excursion during which he came to Louisiana to view and study the Mississippi River and its delta. He reached the city of New Orleans on the 24th of February 1846 by travelling from Mobile through the "inland passage" a natural channel positioned within the offshore bars along the Alabama-Mississippi coast and into Lake Pontchartrain to a landing six miles north of the city. Foremost among the eminent scientists he met with at New Orleans were William Marbery Carpenter and John Leonard Riddell. Dr. Carpenter, first Dean of the Louisiana School of Medicine, had an excellent knowledge of botany and geology and he accompanied Mr. Lyell on an excursion down the Mississippi River to its mouths and on another to Lake Pontchartrain. In 1838, Dr. Carpenter had published an article on Bartram's "fossil forest" at Port Hudson (above Baton Rouge) and was anxious to have his famous visitor examine this section and to render his geological opinion on the locality. Dr. Riddell, professor of chemistry at what is now Tulane University, had calculated from his experiments the proportion of sediment contained in the waters transported annually by the Mississippi River. Charles Lyell utilized the observations of both Carpenter and Riddell and Riddell's experimentally derived figures on river sediments as a basis for his own estimates of the antiquity of the lower delta of the Mississippi River. He further commented on the nature and origin of the "narrow banks, protruded for so many miles into the Gulf of Mexico" and on the relative stability of these banks as demonstrated by comparison of the observed terrane with older maps of the lower delta region. Lyell calculated that the 13,600 square miles of delta must have taken about 67,000 years to form, an observation that is most impressive at this early date.

On March 10, 1846, Charles Lyell left New Orleans and began to ascend the river. At Port Hudson, he disembarked to view the bluffs containing the "fossil forest" as described to him by Dr. Carpenter. Though his examination of Carpenter's locality was greatly hampered by high water, he was able to find a similar buried forest at a higher level and to estimate that changes in the relative levels of land and sea had taken place with a magnitude of approximately 150 feet. At Natchez and at Vicksburg Lyell was able to inspect the great loess bluffs standing 200 feet above the level of the river at Vicksburg and to recognize beneath these wind-transported deposits "a marine tertiary deposit, of the Eocene period, in which we collected many shells and corals." (1849, p. 208)

The visit of Charles Lyell to Louisiana in 1846 was productive and yielded significant observations about Louisiana geology. Especially noteworthy are his comments on the origin of and age of the lower delta, the nature of and origin of Lake Pontchartrain, his descriptions of the exposed Tertiary strata and the overlying loess deposits in the bluffs near Vicksburg, his views on the "fossil Forest" in the bluffs at Port Hudson, and his discussions of the evidences for subsidence and the probable rates of this subsidence in both the Port Hudson area and in the lower deltaic plain of the Mississippi River. For a more complete account of Lyell's observations see *Charles Lyell in Louisiana* (Skinner, 1976, p. 243-248) and for Lyell's own descriptions of his excursions in Louisiana see *A Second Visit to the United States of North America* (Lyell, 1849, v. II, p. 110 *et seq.*).

RAYMOND THOMASSY

Marie-Joseph Raymond Thomassy (1810-1863), a French hydraulic engineer, came to the United States about 1850 and visited New Orleans where he became fascinated with the dynamic power of the Mississippi River and the physical characteristics and origin of the coastal plain of Louisiana. His intense interest and scientific curiosity resulted in *Gĕologie Pratique de La Louisiane*, published by the author in New Orleans in 1860.

Thomassy was proud, arrogant, ambitious, and an ardent French nationalist. These characteristics produce an unfortunate bias in his work, which must be reconciled before his ideas can be reviewed and evaluated. On one occasion, his arrogance in comparing the Mississippi River unfavorably with rivers in France led to a challenge from a Creole gentleman to a duel over the honor (and power) of the Mississippi River. Thomassy survived the duel with only a painful and disfiguring

facial injury to remind him of the incident.

In his *Géologie Pratique*, Thomassy suggested that the study of the alluvial lands would provide the key to the great problems of Louisiana geology, and throw light upon "analogous terrains of anterior periods." He discussed mineral springs, artesian wells, mud springs and mud lumps, in addition to hydrothermal and volcanic forces and the evidence for subterranean convulsions in forming the Five Islands of southern Louisiana. He stated the need for a map depicting soils and agriculture, and listed native raw materials or "treasures" that should be exploited for the good of the people: plaster, kaolin, plastic clays, limes, and hydraulic mortars.

Thomassy considered the role of water to be the greatest and most active of the geologic "forces" which contributed to the formation of Louisiana, but he considered "volcanic forces" also to be major in importance, especially in the origin of the Five Islands and the mud lumps. He recounted in detail the history of the discovery of the Mississippi River and presented a series of maps depicting the changing nature of the lower delta region.

Thomassy considered the Five Islands, a series of emergent salt domes, to be formed by some sort of volcanic action, concentrated from the saline waters by hydrothermal forces, and elevated by aqueous eruption. He suggested that the salt masses could be exploited as a source of salt. In 1861-1862, the effects of the Civil War resulted in the sinking of pits or shafts at Avery Island (then called Île Petite Anse) to mine salt for local use. Upon receiving word of confirmation of his salt intrusion theory in the origin of these domes, Thomassy returned to Louisiana from France to view the salt pits and to write a supplement to his earlier work (Thomassy, 1863).

Raymond Thomassy described the delta as a mixture of fluvial and marine origins and gauged its advance at 100 meters per year or one mile in sixteen years. He noted a most salient characteristic, the deviation of the lower course of the river from its southward course toward the southeast, and reported on marine shells recovered from sediments beneath New Orleans. Much of the text deals with hydrography, drainage and other engineering problems, subterranean hydrology, submarine hydrology and related topics, most of which is of limited geological interest; however, this is to be expected as he was primarily a hydraulic engineer.

Thomassy's observations are significant and important. He was the first to describe the emergent domes of the Five Islands as salt intrusions and the first to attempt to explain their origin. He figured and described the mud lumps near the mouths of the river and attempted to explain them. He presented a series of maps illustrating changes in the Louisiana coastline between 1684 and 1859, especially in the area of the present Balize delta, and computed the rate of advance of the delta at 100 meters per year. His work was the first comprehensive effort to describe the geology of Louisiana, a monumental project at this early date. For a more complete account of Thomassy and his work see Skinner (1979, in press).

EUGENE W. HILGARD

Eugene Waldemar Hilgard (1833-1916), born and educated in Germany, was State Geologist of Mississippi (1858-1860) and professor of chemistry at the University of Mississippi (1865-1873). In 1867, under the direction of the Smithsonian Institution, Hilgard made a trip down the Mississippi River and to the central three of the Five Islands. The preliminary report on this reconnaissance work appeared in the *American Journal of Science* in 1869. He considered the rock salt to be produced by evaporation from a lagoon or a series of lagoons, overlying early Quaternary marine clays. The Five Islands were interpreted simply as accidents of differential erosion. Later in 1869 *Summary Results of a late Geological Reconnaissance of Louisiana* appeared in the same journal. The geological "terranes" recognized included:

Alluvium	
– – – – – – – – – – – – – –	
Port Hudson Group	350 to 600 feet
Orange Sand Group	100 to 175 feet
Grand Gulf Group	sand and claystones
Vicksburg Group	c. 50 feet of marine Tertiary beds
Mansfield Group	lignitiferous beds
– – – – – – – – – – – – – –	

Cretaceous Formation	907 feet of limestone sulphur and gypsum beds

To explain the occurrence of the Orange Sand, he suggested that "in late Quaternary times the Gulf coast has suffered a depression to the extent of at least nine hundred feet (perhaps more), and during the Terrace epoch, a contrary motion of about half that amount." He continued with a discussion of *Salines of Northern Louisiana,* including the methods of producing brine from wells from 15 to 1100 feet in depth, and described the artesian wells of Calcasieu at "the head of the bayou Choupique." At the Troy meeting of the American Association (1869), Hilgard read *On the Geology of the Delta and the Mud-lumps of the Passes of the Mississippi,* in which he stated that the delta plain is covered by river deposits only to a "comparatively insignificant depth." The mud-lumps are discussed at length and are attributed to eruption of a mixture of mud, water, and combustible gas.

In 1871 *On the Geological History of the Gulf of Mexico* was read before the American Association, describing a Cretaceous "backbone" passing through the state to the north and northwest with the strata dipping away on either side. In 1872, a Smithsonian memoir *Geology of Lower Louisiana and the Rock Salt of Petite Anse* expanded his views on the origin of the rock salt, and attributed the Five Islands to erosion-formed outlier remnants of a Cretaceous ridge or "backbone" traversing Louisiana, which though once covered by Tertiary deposits had been exhumed. The salt he considered to be of Cretaceous age.

Hilgard's *Supplementary and Final Report of a Geological Reconnoissance of the State of Louisiana,* a 44 page pamphlet published in 1873 under the auspices of the New Orleans Academy of Sciences and of the Louisiana Bureau of Immigration, was termed by Harris and Veatch (1899, p. 29) "the most complete statement of the geology of the State heretofore published." They recommend that "It should be consulted by any and all who care to become familiar with the geology of the State." It certainly is the most complete and definitive work by Hilgard on the geology of Louisiana.

Subsequent work by Hilgard important to Louisiana geology includes *Note on Lignite beds and their Under-clays* (1874), *The Later Tertiary of the Gulf of Mexico* (1881), *Salines of Louisiana* (1883), *Report on Cotton Production in the United States* containing a brief summary of the geological features of Louisiana (1884), *The Classification and Paleontology of the United States Tertiary Deposits* (1885), *The Old Tertiary of the Southwest* (1885), and *The Equivalence in Time of American Marine and Intra-continental Terranes* (1887). For a longer and more complete account of Hilgard's work in Louisiana see Harris and Veatch (1899, p. 23-32).

GILBERT D. HARRIS

Gilbert Dennison Harris (1864-1952) attended Cornell University (1883-1888) and graduated in 1886 in the same class with Robert T. Hill and David White. He pursued graduate study in geology under Henry S. Williams but left Cornell in 1888 to take a position with the Arkansas Geological Survey. The following year, Harris joined the United States Geological Survey where he worked first in the Paleozoic Division and later under William H. Dall in the Cenozoic Division. He continued with his work in Arkansas during 1891-1892 and as a part of this work made his first excursion to Louisiana (see above); the results of his studies of the Tertiary deposits of Arkansas appeared (1894) in volume II of the Arkansas Geological Survey *Annual Report for 1892.*

In 1894, Gilbert D. Harris was appointed to the faculty at Cornell and remained there until his retirement in 1934. For a full treatment of the life and scientific accomplishments of Gilbert D. Haris see Katherine Van Winkle Palmer's *Memorial* (1953), the main source of much of the material in the present narrative.

In 1898, while teaching at Cornell, Harris was appointed Geologist-in-charge to the Geological Survey of Louisiana, and continued in this capacity until 1909. He spent mid-December to late March each year in Louisiana, teaching during the summer and fall at the University and working on reports of the previous field season for the Survey. His capable student, Arthur C. Veatch, became Harris's assistant on the Survey and an instructor at Cornell. Veatch worked in Louisiana for

most of the year 1898 and, in the following year, the first extensive work (354 pp.), *A Preliminary Report on The Geology of Louisiana,* appeared under the joint authorship of Harris and Veatch (1899). This comprehensive report remains even today a standard reference on the geology of Louisiana. After an historical review of previous work on the state, the stratigraphy and economic geology of Louisiana are considered in detail, followed by nine special reports on the geology of specific areas, faunas, floras, surveying, and mapmaking. Among the special reports, *The Five Islands* by Veatch, and *The Cretaceous and Lower Eocene Faunas of Louisiana* by Harris, are of special significance. A *Geological Map of Louisiana* with the outcrops of the strata indicated by colored patterns accompanied the stratigraphic portion of the *Preliminary Report.*

Three years later, *A Report [of 1902] on The Geology of Louisiana,* was published, based on the work of the 1900, 1901, and 1902 field seasons. Jov. A. A. Pacheco, *Assistant Geologist,* joined Harris and Veatch as one of the principal authors for the 1902 report. It consists of eight special reports similar in scope to those in the *Report for 1899;* three are by Gilbert D. Harris, three are by Veatch, one is by Harris and Pacheco, and one is by R. A. Harris of the United States Coast and Geodetic Survey. The first of the reports, *The Tertiary Geology of the Mississippi Embayment* by G. D. Harris, is of special importance in placing Louisiana and its geology into regional perspective and into the general structural framework of the Gulf of Mexico region. A colored map of the Tertiary deposits in the central embayment area, including the state of Mississippi and parts of Arkansas and Tennessee in addition to Louisiana, is a part of this special report. The eighth report, *Oil in Louisiana,* also by G. D. Harris, reviews the beginning of oil exploration activities in Louisiana.

Later in 1902, Veatch left the state survey for the United States Geological Survey to prepare a report on the geology and underground water resources of Louisiana, which ultimately appeared as USGS Professional Paper 46 in 1906. Pacheco remained with Harris and was joined by Leopold Reinecke, Francis L. Whitney, John L. Rich, and several others who served as field assistants for Harris during the next few years.

The *Geological Survey of Louisiana Report of 1905* [published 1907] comprises four papers by various authors based on the 1903, 1904, and 1905 field seasons. These four papers are designated as *Bulletins I, II, III,* and *IV* on the title page of the collected volume, but may be found as separate numbered bulletins of the [first] Louisiana Geological Survey; these are somewhat less common than the collected volume, *Report of 1905.* In similar fashion, the *Report of 1907* contains numbered *Bulletins* 5, 6, and 7 of the Louisiana Geological Survey, each dealing with a discrete subject on some aspect of Louisiana geology or hydrology.

With the establishment of the Geological Survey of Louisiana under the direction of Gilbert D. Harris, the initial or formative period in the comprehension of the geology of Louisiana came to an end. The Harris Survey brought systematic order to the investigation of Louisiana geology and inaugurated the modern period of study.

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November 9, 1979

REVIEW

PALEOLITHIC SITE OF THE DOUARA CAVE AND PALEOGEOGRAPHY OF PALMYRA BASIN IN SYRIA, Part I: Stratigraphy and Paleogeography in the Late Quaternary, edited by Kazuro Hanihara and Yutaka Sakaguchi. Published by the University of Tokyo Press, 1978, vi + 121 pp., illustrated. Distributed by ISBS, Inc., Forest Grove, Oregon, ...$29.50

The Douara Cave was discovered in 1967 and was found to have been a habitation site for Neanderthal man. This is a report of the 1974 survey of the cave area by the Tokyo University Scientific Expedition to Western Asia.

Douara Cave is about 200 km northeast of Damascus, Syria and only 18 km from Palmyra, the well-known oasis town. The stratigraphy of the deposits and paleoenvironments are discussed in addition to descriptions of the stone implements and other cultural materials. Evidence for the probable remains of a factory site for stone implement manufacture is presented and the site is compared with other similar discoveries in the Palmyra Basin.

Although this work is probably of primary interest only to anthropologists, its significance to the study of fossil man may appeal to a much broader readership among geologists and biologists interested in human paleontology.

—H.C.S.

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RHYTHM OF THE PALEOCENE-EOCENE SEAS OF THE CENTRAL GULF COAST, AS DEFINED BY FOSSILS AND SEDIMENTS

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The Paleocene-Eocene strata of the Gulf Coastal Plain occupy the general area from southwestern Texas eastward through Alabama and north as an arc in Arkansas, Kentucky, and Tennessee. The greater mass of the formations of this region are shallow water, marine clastics—arenaceous, argillaceous, calcareous, and glauconitic. Alternating stages of marine and nonmarine deposits (with fossils of land plants) characterize the sediments in the area.

The marine formations abound with well-preserved fossil invertebrates. At certain localities immense collections may be obtained, attesting to past prolific marine life. In both surface and subsurface formations the members of the Foraminiferida, large and small, are excellent zonal markers. Although representatives of sponges, corals, brachiopods, bryozoans, ostracodes, and crustaceans are present, mollusk shells exceed all other invertebrate megafossils in abundance. They are useful as surface guides to formations and to the discrimination of the stratigraphic stages. Outstanding in the fossil population of the southern coastal area are the mollusks made famous by those from Claiborne Bluff, Alabama River, in Alabama.

Because of their prominence at many distinct localities in the regional unit, their splendid preservation, and their coherent biologic and geologic history, the mollusks are a profound factor in the interpretation of the history of the Paleocene-Eocene embayments of the Gulf Coast. For over 150 years, by more than a score of authors, the fossils have been collected, studied, described, and illustrated. The formations have been equally investigated, correlated, and the stratigraphic column standardized with general agreement. Published studies on the mollusks include everything from brief papers to monographs of over 500 pages, with illustrations up through 90 plates. A wealth of data on the molluscan species has been accumulated as to origin, correlation, variation, similarities, biologic relationships, geographic extent, stratigraphic range, environmental aspects, and other pertinent factors. Palmer and Brann (1965) have listed some 2400 species and recent investigations continue to increase the number.

From this wealth of detailed studies of the fossils and sediments substantial deductions can be made as to the sequence of events through the Paleocene-Eocene time of the southern coastal embayments. Because of the many natural exposures with their well-preserved stratigraphic sections extending laterally and vertically, the area is renowned as a standard of Paleocene-Eocene Paleontology and Stratigraphy, a so-called "classic of lower Cenozoic history."

Though equivalency of separate sections may not be totally agreed upon, the correlation of the major units is of general approval. The sediments and fossils have been grouped into time-rock units (Stages) of a four-part general designation:

1. Paleocene *Midway Stage* — type area, Alabama. MARINE PHASE.
2. Eocene (lower) *Sabine Stage* — type area, Sabine River, Texas and Louisiana. MARINE AND NON-MARINE PHASES.
3. Eocene (lower middle) *Claiborne Stage* — type area, Alabama. MARINE PHASE. Eocene (upper middle) *Claiborne Stage* — type area, Alabama. MARINE AND NON-MARINE PHASES.
4. Eocene (upper) *Jackson Stage* — type area, Mississippi. MARINE PHASE.

The period of time of these Stages represents a sequence of transgression, regression; transgression, recession; transgression and final regression — presenting three periods of flood in the Paleocene-Eocene and two times of general retreat of the mother Gulf waters in the southern Coastal Plain (see figure 1).

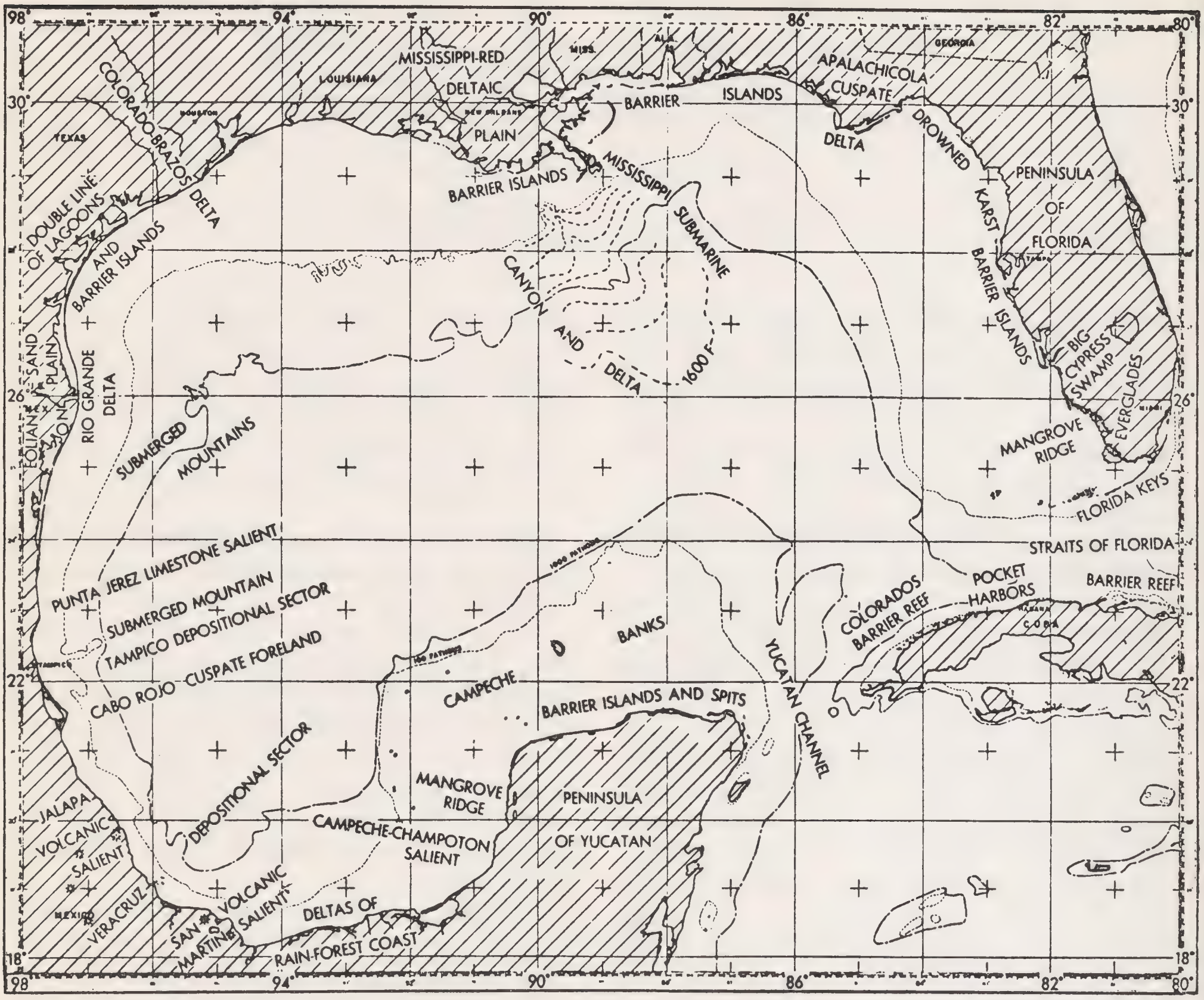
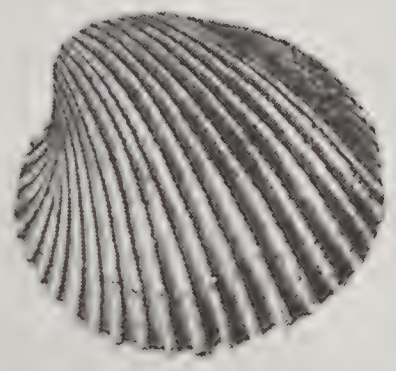


Figure 1. Shorelines and major geographic features of the Gulf of Mexico. (After Price, 1954). Courtesy L.D. Toulmin.

Such an analysis of the movements of rhythm of the lower Cenozoic Gulf waters would suggest five Stage (time-rock) units instead of four as presently generally outlined. Five stages were stipulated by the late G.D. Harris in 1918, 1919 as: *Midway,* marine; *Sabine,* lignitic (non-marine); *"St. Maurice,"* marine; *Claiborne,* lignitic (non-marine); and *Jackson,* marine. I subscribe to the Harris division of stages, with the exception of using the name "St. Maurice" for the third stage; however, we should limit "Claiborne" to the upper-middle Eocene as a stage. This would include the marine Gosport Sand and the non-marine sediments elsewhere. I would hope that a separate name for the marine lower-middle "Claiborne" can be provided in place of "St. Maurice" or "lower Claiborne." If the 4-part table of stages is used, an adequate image of the upper middle Eocene interval is not truly presented. To use the term "Gosport Sand" as representing the recession in the so-called "Claiborne" Stage is misleading as to the nature of the strand line. The fossils of the Gosport Sand are famous and their reputation dominates the general image of the southern American Eocene. The fauna of the Gosport Sand represents a concentration of marine invertebrate remains, particularly mollusks, piled in a small area of the total region involved in the stage. Other than the marine phase of the Gosport Sand, the sediments of the stage are generally nonmarine and represent the recessional

Paleocene	Lower Eocene	Middle Eocene		Upper Eocene
		L.M.U. Claiborne gr.	Gosport sd.	
	Venericardia alticostata "var."	Venericardia angustoscrobis	Venericardia aldrichi	
Venericardia bulla	> V. aposmithii	V. bilineata	V. alticostata	
V. crenaea	V. ascia	V. blandingi		
V. eoa	V. bashiplata	V. brittoni		
V. francescae		V. carolinensis		
V. gardnerae		V. claiboplata	> V. claiboplata	
V. hesperia				
V. hijuana		V. claviger		
V. jewelli		V. complexicosta		> Venericardia apodensata
V. mediaplata		V. cookei		V. cookei
V. mingoensis		V. densata		V. diversidentata
V. moa	V. densata pendletonensis	V. eutawcolens	V. diversidentata sym-	V. d. symmetrica
V. m. "n. subsp."			metrica	V. d. "var."
V. regia	V. greggiana		V. inflatior	V. inflatior jacksonensis
> V. smithii	V. gulielmi			V. klimacodes
V. whitei	V. hatcheplata	V. klimacodes		V. ocalaedes
V. wilcoxensis	V. horatiana	V. leonensis		
V. spp.	V. intermedia	V. mooreana		
	V. nanaplata	V. natchitoches		
	V. n. nanna	V. parva	V. parva	V. parva "var."
	V. pilsbryi			V. praecisa
	V. potapacoensis			V. vicksburgiana
	V. sabinensis			V. withlacoochensis
	V. turneri			V. spp.



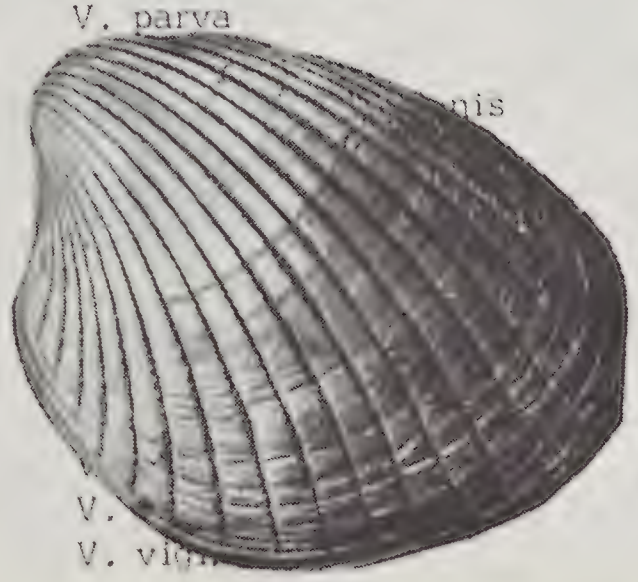


Fig. 2 Representative species of Venericardia planicosta stock, Gulf Coastal Area, Paleocene-Eocene (after Palmer and Brann, 1965, pp. 60-61)

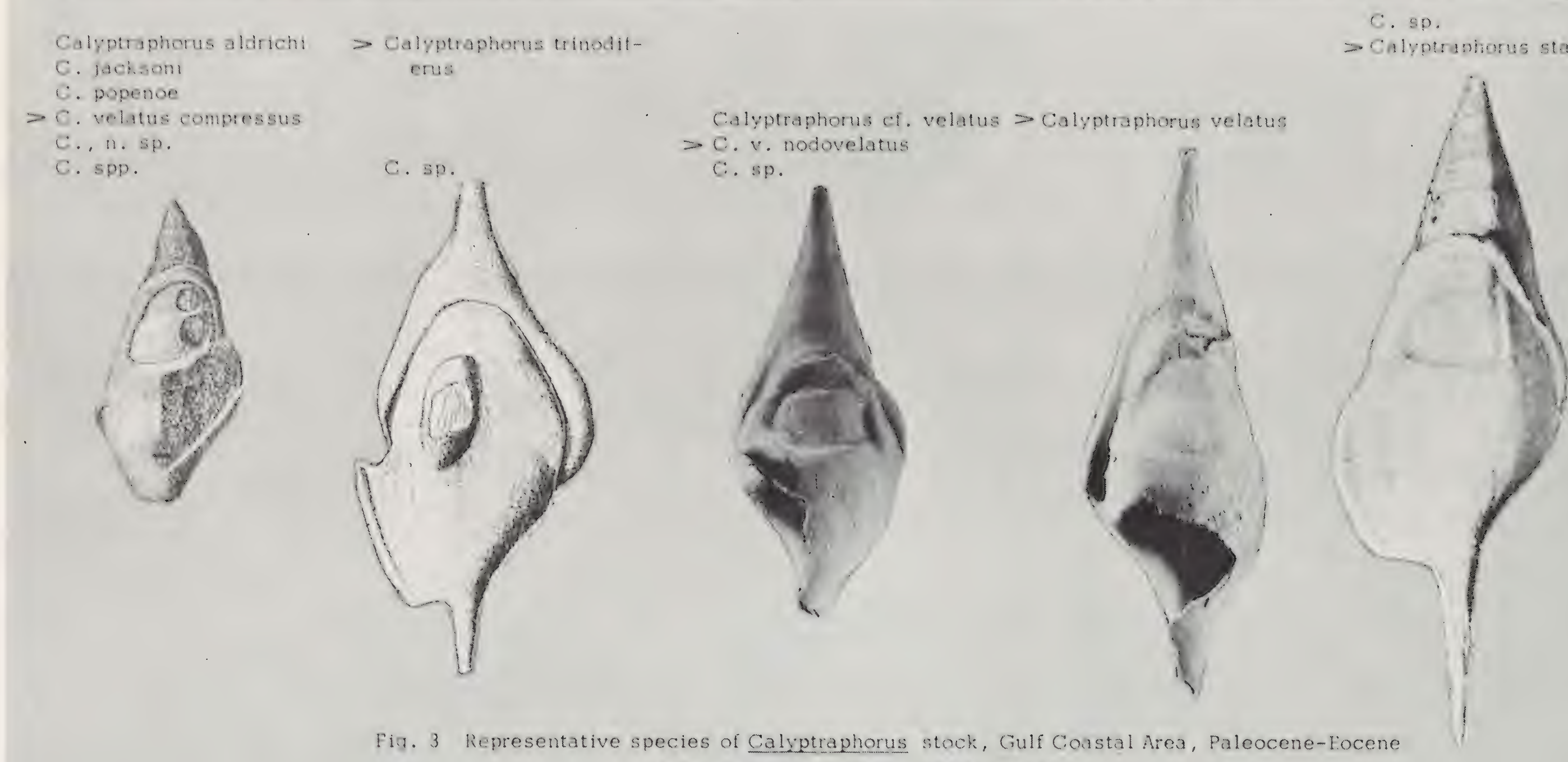


Fig. 3 Representative species of Calyptraphorus stock, Gulf Coastal Area, Paleocene-Eocene (after Palmer and Brann, 1966, p. 1032)

Fig. 4 Representative species of Athleta stock, Gulf Coastal Area, Paleocene-Eocene (after Palmer and Brann, 1966, p. 1030)

movements between the marine "Lower Claiborne" Stage and the wide inundation of the marine upper Eocene Jackson Stage.

General charts (46 pp.) of the distribution of the approximate number of 2400 molluscan species by stages have been outlined by Palmer and Brann (1965, 1966). Three of those charts are presented here (figures 2, 3, 4). The charts shown also depict the development of certain stocks of lineages occurring in the time from Paleocene through upper Eocene. Such genera as *Venericardia, Ostrea, Calyptraphorus, Athleta,* and *Pseudoliva,* are examples of the inherent character of the fauna, which through the millions of years of the Paleocene-Eocene dominated the region but evolved specifically with change of time and environment in the stages. The figures depict the species of each stock that is the particular guide to each stage.

The sequence of certain lineages also exploits and illustrates the biologic changes influenced by the shiftings in the strand line. Those changes G.D. Harris summarized in 1918 as the "Flow and Ebb of the Eocene Seas." That cyclic routine is the "Rhythm" of the time and seas. The term "cyclic," or the term "rhythm," is not new but has been utilized by many researchers such as Barrel (1917 - "cyclic"), Weller (1930 - "cyclic"), Hudson (1924 - "rhythm"), Plummer (1933 - "cyclic"), and Murray (1961). In addition, Ellisor (1929), Fisk (1938), Hunter (1939), Stenzel (1938, 1952), and many others (for references see Murray, 1961) have expounded on the phenomenon of sediments in strand line changes, particularly with the units in the "Claiborne" Stage. The Paleocene-Eocene of the Gulf Coastal area is a prime example of the alternating facies that have occurred within the boundaries of the embayment and the accompanying evolution in the fauna. This phenomenon may be depicted as a rhythm of the lower Cenozoic.

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(Continued on p. 94)

AN OVERVIEW OF THE TERRESTRIAL EARLY TERTIARY OF SOUTHERN NORTH AMERICA — FOSSIL SITES AND PALEOPEDOLOGY

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ABSTRACT

Increasingly detailed stratigraphic work in intermontane basins from Montana to Texas has revealed significant differences between northern and southern early Tertiary terrestrial faunas of western North America. Paleontological data from southern California, Mexico, New Mexico, and west Texas allows analysis of the effects of topography and climate on southern faunal distribution. Endemism in the Paleocene and Eocene of southern California and the Paleocene of west Texas can be attributed in part to geographic isolation. Observed differences between northern and southern faunas are tied to climatic differences, which are traceable from locality to locality using paleopedology. For example, Paleocene fluvial mudstones in west Texas and New Mexico show prominent red and black banding. Red layers are rich in soil-formed calcite nodules. Red color-banding and nodules are not widespread in northern localities until the early Eocene, indicating a northward spread of warm, variable climate. Migrations of animals, triggered by such climatic changes, may be responsible for abrupt faunal changes in the northern intermontane basins.

Early Tertiary fossil vertebrate sites are scarce east of the Big Bend region of Texas now, but within a decade lignite strip mining in east Texas, Louisiana, and Arkansas will be producing outcrops. The best hope for finding extensive early Tertiary terrestrial faunas in eastern North America lies in the Gulf Coast.

The early Tertiary Gulf Coast may have served as a source for new forms migrating to the west and north. The Paleocene and early Eocene faunas of the southeastern U. S. can be expected to have strong European affinities, and the late Eocene to have close ties to western North America. The Paleocene faunas of west Texas show less resemblance to those of France, which were similar in latitude, than the high degree of similarity of early Eocene animals of Europe and western North America would have suggested. Evidently, neither the slow-to-open North Atlantic nor the long distances were insurmountable barriers to many mammals before the end of the early Eocene. The Cretaceous interior seaway split North America and served as a barrier to migration between west and east Texas. The effects of this separation may have lingered throughout the Paleocene.

INTRODUCTION

Several recent developments make this a good time to look both backwards and forwards at the terrestrial Paleocene and Eocene of southern North America. A revision of terrestrial Cenozoic chronology edited by M.O. Woodburne is in preparation and should be published within 1979 or 1980 (Woodburne, 1978, pers. comm.). Although many aspects of this summing up of available data on Cenozoic chronology will be highly controversial, it should serve as a reference point for decades, as its predecessor by Wood *et al.* (1941) did. A great deal of new stratigraphic data has become available recently. Detailed stratigraphic studies such as those of Gingerich (1976) are making possible a much greater precision in examining past evolutionary and paleoecologic events. New dating and fossil-collecting techniques and changes in the legal status of pre-Pleistocene fossils also provide an increasingly detailed background against which attempts can be made to correlate paleontological data on animal distributions with information on small scale environmental changes, available from studies of depositional environments and paleopedology.

ADVANCES IN TERRESTRIAL PALEONTOLOGY

Screen washing for microvertebrate fossils (Hibbard, 1949; McKenna, 1962) is increasing the value of vertebrate fossils as stratigraphic tools. It greatly increases sample sizes and recovers rare material

from sediments essentially barren to surface hunting and quarrying. For example, a screen washing of approximately one ton of sediment from a single Paleocene site in west Texas yielded 19 genera (Schiebout, 1974), three times the total previously known from the whole formation (Wilson, 1967). New techniques of sorting fossils from concentrate (screen wash residue), such as the heavy liquid method reported by Murray and Lezak (1977), will make this technique more and more useful.

New dating techniques and increasing application of old ones are producing a more reliable framework for reconstruction of early Tertiary events. For example, radiometric dating of volcanic rocks intercalated with vertebrate-bearing sediments is producing better resolution of the age of many classic sites. A magnetic reversal scale for the terrestrial early Tertiary is also being developed (Berggren *et al.*, 1978; Lindsay *et al.*, 1978).

Widespread acceptance of the idea of plate tectonics has revolutionized paleogeography and spurred interaction of paleocologists in testing reconstruction of continental positions and latitudes. The recent work of Dawson *et al.* (1976) and West *et al.* (1977) in the Eureka Sound Formation of Ellesmere Island is an example of "continental drift" providing incentive for investigation of a new and unusual area for vertebrate fossils. Drift theory and paleobotanical evidence had led McKenna (1972a, 1972b, 1972c, 1975) to consider an early Tertiary North Atlantic migration route for terrestrial animals between North America and Europe. Dawson *et al.* (1976) reported a small Eocene fauna of vertebrates which supports the idea that a warm temperate climate extended to 80° north latitude. A symposium entitled "Cenozoic History in and around the northern Atlantic and Arctic Oceans" at the 1978 Geological Society of America Annual Meeting drew workers interested in reconstructing early Tertiary conditions in this region from a wide variety of disciplines. The early Eocene (Wasatchian) mammalian faunas of North America show at last 50% generic similarity to those of Europe; such similarity is not repeated again and drops to 10% in the Bridgerian (Dawson *et al.*, 1976), suggesting that this marks the severance of the North America-to-Europe migration route (see summary of Berggren *et al.*, 1978).

Both problems and opportunities arise from changes in the legal status of vertebrate fossils and from extensive mining and other disturbances that will affect early Tertiary terrestrial deposits more and more frequently in the future. A debate is underway between federal officials and the paleontological community regarding the applicability of such legislation as the Antiquities Act of 1906, the National Environmental Protection Act, and the Moss-Bennett Bill to those paleontological materials not associated with anthropological or archaeological material. The National Heritage Act of 1972 specifically includes paleontological materials for protection, and new legislation specifically aimed at providing salvage procedure for such fossils can be expected in a few years (Mc Kinney, 1978, pers. comm.). Marshall (1976) provided a review of the legal status of paleontology in the U.S. at that time.

At present, regulation often means that scientists and conscientious amateurs are excluded from areas where vandals and ill-trained amateurs continue to roam at will. As the historical, scientific, and aesthetic values of vertebrate fossils are gradually communicated to the bureaucracy responsible for regulating antiquities, better cooperation between government agencies and scientists should develop. As paleontologic remains come to be regarded as a natural resource, they can no longer be blithely ignored by miners and land developers. Availability of funds for survey and salvage, long a boon to archeologists, is beginning to extend to paleontologists. An example is the Bureau of Land Management-sponsored survey in 1977 by the University of New Mexico and Louisiana State University of 4½ million acres of land in the San Juan Basin (Kues *et al.*, 1977). Cretaceous and early Tertiary paleontologic resources threatened by coal strip mining were the specific target of the study (Fig. 2). Opportunities for employment for paleontologists, particularly vertebrate paleontologists, with governmental agencies and industry are likely to increase in the future and museums can expect large, sometimes overwhelming, increases in specimens recovered in salvage work. A concurrent flood of new data on the

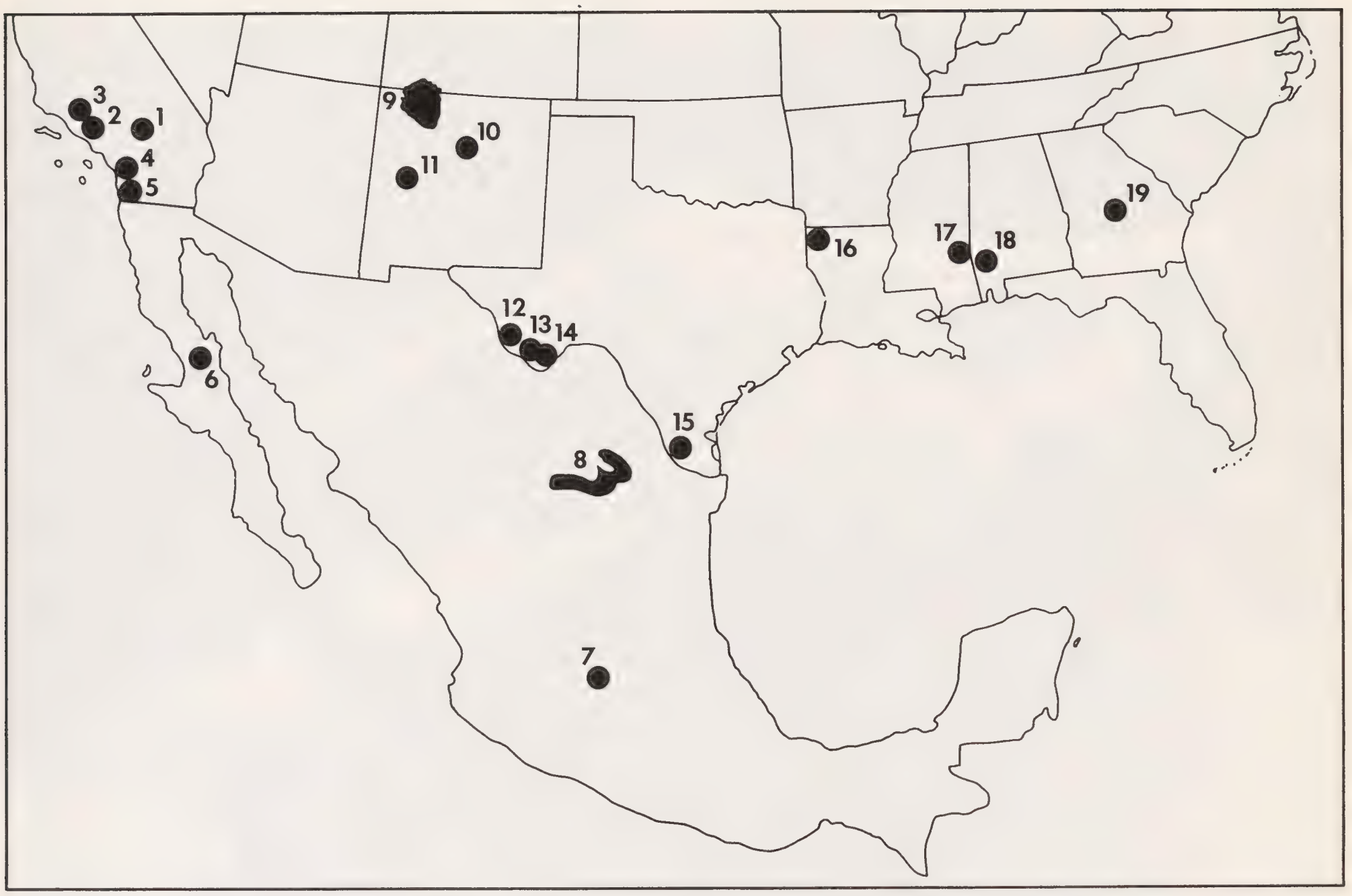

Figure 1. Index Map to Paleontological and Paleopedological Localities. *Paleocene:* 1, Goler Formation locality; 5, San Diego County; 6, Punta Prieta; 9, San Juan Basin; 14, Big Bend National Park; 16, Caddo Parish. *Eocene:* 2 & 3, Ventura Basin; 4 Carlsbad; 5, San Diego; 7, Guanajuato; 8, Parras and La Popa Basins; 9 San Juan Basin; 10, Galisteo Formation locality; 11, Baca Formation locality; 12, Vieja; 13, Agua Fria; 14, Big Bend National Park; 15, Laredo; 17, Clark County; 18, Little Stave Creek; 19, Twiggs County.

early Tertiary of North American can also be expected.

A fossil "gold rush" in the last quarter of the 19th century set the stage for modern work on the terrestrial early Tertiary of North America. Deposits that are still considered the best terrestrial fossil-bearing Paleocene and Eocene sites in the world were discovered in the American west, and fossils streamed back from Wyoming, Colorado, and New Mexico, to eastern museums. The Cope-Marsh feud raged, leaving a legacy of over-split early Tertiary taxa. The concepts of the North American Land Mammal Ages of the Paleocene and Eocene, which are currently in use, developed through work on the fossils preserved in the intermontane basins of Wyoming, Colorado, and New Mexico. Wood *et al.* (1941) attempted to standardize these subdivisions as biostratigraphic units but the definitions of many remained tied to well-known rock units and the names remain a link to western history. The redefinition now in progress should bring use of these terms more into line with modern stratigraphic practice. From oldest to youngest, the Paleocene is divided into the following Land Mammal Ages: Puercan, Torrejonian, and Tiffanian. The Eocene is divided into the Wasatchian, Bridgerian, Uintan and Duchesnean. Some specialists consider the Clarkforkian wholly Eocene and others partly Paleocene and partly Eocene. Future papers on its placement can be expected shortly (Sloan, 1978, pers. comm.; Gingerich, 1978, pers. comm.).

PALEOCENE AND EOCENE PALEOCLIMATE

The emerging large-scale picture of North American Paleocene and Eocene paleoclimate is a synthesis of many lines of evidence. Frakes and Kemp (1972) sum-

Figure 2. Skull of *Claenodon ferox* in place as discovered in the Naciemiento Formation on the 1977 paleontological survey in the San Juan Basin. Specimen is approximately 13 cm long. Photo by A. K. Schrodt.

marized information on Paleocene and Eocene climate worldwide and integrated it with plate tectonic data. Wolfe (1978) provided a summary of foliar physiognomy data in tracing North American Tertiary large scale climatic changes, which he attributes to changes in the earth's inclination. Paleobotanical data derived from palynology and the study of leaf form, and paleontological data derived from a slowly developing picture of animal migrations and from the ranges of animals with temperature-limited distributions, such as crocodiles and alligators, must be joined with data on paleogeography. For example, Miocene Basin-and-Range faulting produced generally north-south trending ranges that isolated parts of the American southwest from moisture-bearing winds and produced a degree of aridity not seen in the early Tertiary. The lack of polar ice caps, considered by Savin (1975) to have formed in the Miocene, would also have produced a less latitudinally-stratified early Tertiary climate in which the subtropical conditions postulated for Ellesmere island could fit.

Work by Sloan (1969) and Van Valen

and Sloan (1977) has documented early-Tertiary animal distribution patterns, which may have been climate-controlled. Sloan (1969) recognized distinctive northern and southern Paleocene faunas separated by an east-west line running through southern Wyoming. A large Paleocene fauna from Trans-Pecos Texas, the southernmost large assemblage of mammals of this age from North America, agrees with some of his generalizations (Schiebout, 1974, p. 44). New information suggests that the continental divide may have shifted from west to east of the San Juan Basin in the Tiffanian (Sloan, 1977, pers. comm.) so that elements previously considered "northern" in the west Texas fauna may in reality be due to both faunas being east of the divide. This could explain puzzling differences between the Paleocene faunas of west Texas and the San Juan Basin, 850 kilometers away. Van Valen and Sloan (1977) considered the shift in faunas marking the Cretaceous-Tertiary boundary in Montana to be the result of a shift southward of temperate coniferous forest displacing subtropical deciduous ones. Savin (1975) provided oxygen isotope data for late Cretaceous cooling; McLean (1978) postulated a brief, intense warm spell at the Cretaceous-Tertiary boundary. The fauna that marks the base of the Eocene in the well-studied northern intermontane basins is considered to have shifted in response to a northward spread of subtropical climates after a warm temperate interval in the Tiffanian (Sloan, 1969). Gingerich (1977, p. 497) discussed the correlation between major climatic warming periods seen in the early Eocene, early Oligocene, early Miocene, and early Pliocene, and high latitude intercontinental migration such as that noted between North America and Europe in the Wasatchian. Estes (1976) briefly discussed the effect of early Tertiary climatic shifts on the lower vertebrates of North America.

No single fixed north-south geographic barrier is known for the early Tertiary of the American west. The northern extent of the San Juan Basin of new Mexico and Colorado has been selected as the northern boundary delineating the "south" for the purposes of detailed discussion of sites in this paper. No single line could separate all northern and southern features, and northern and southern faunas are known to have shifted. The San Juan Basin Paleocene and Eocene faunas are among the best known southern early Tertiary deposits of North America. They, and deposits further south both east and west of the Paleocene continental divide, can serve to characterize southern sites and associated paleopedological climatic indicators.

Information on paleopedology is beginning to be used in conjunction with paleontological data to reconstruct local climates for individual Paleocene vertebrate localities. Soil-formed color banding in overbank mudstones has been recognized as a climate indicator by vertebrate paleontologists for over 60 years. Sinclair and Granger (1911, p. 116-117) considered color banding in mudstones in the Eocene and Oligocene of the Wind River and Bighorn basins to be a result of recurring moist and arid climatic cycles. Color banding has been used to reconstruct details of temperature and rainfall for individual early Tertiary paleontological sites only in the last decade (Schiebout, 1970, 1974, 1978; Bown, 1975, 1977). For example, Schiebout (1970, 1974), working in the Paleocene of West Texas, described color banding in overbank muds of the fluvial Black Peaks Formation as indicative of alternating wet and dry post-depositional conditions of greater than seasonal duration in a semitropical to tropical climate (Fig. 3). Red bands rich in soil-formed microcrystaline calcium carbonate nodules developed during dry periods when flood-deposited alluvium dried out and water tables were low. Black layers, colored by organic matter, formed in wet periods when the water table stayed at or above the alluvial surface, producing reducing conditions. During these periods, the floodplain may have resembled parts of the modern Amazon Basin (Sioli, 1951, p. 279) and the Atchafalaya Basin of Louisiana where heavy forests grow in standing water. According to Van Houten (1948, 1973), discussing North American early Tertiary banded beds, recently-deposited alluvium would have been drab, probably brownish in color and the eventual red color would have been a result of dehydration of inherited iron oxides plus in-place oxidation of iron-bearing minerals in the floodplain soils. Gray zones and mottled areas were the product of reduction.

Figure 3. Color banding in mudstone of the Paleocene Black Peaks Formation in Big Bend National Park, Texas. Two red layers are separated by light gray layers from a prominent black band (arrow). Meter stick for scale.

The presence of calcium carbonate nodules is becoming widely recognized as an indicator of semiaridity (Steele, 1974; Mc Bride, 1974, 1975; Pierce and Peterson, 1975). According to Freytet (1973), nodule formation occurs in the zone of oscillation of a phreatic water table. Cracks, narrowing toward the outside of the nodule, are common in nodules of the west Texas Paleocene. The cracks indicate wetting and drying, and thus are consistent with Freytet's model of nodule formation. The exact role of calcium carbonate availability in nodule formation remains to be clarified. For example, thick Pleistocene caliches in the Jornada Basin of New Mexico are attributed by Seager and Hawley (1973) to leaching of abundant wind-deposited carbonate dust from upper soil layers. Carbonate availability may greatly modify the time needed to form nodules and the range of climates in which they can form.

The color bands are not facies indicators as such because they are post-depositional features. Regional climatic factors, including amount and periodicity of rainfall and annual temperature means and ranges, affect the pattern of ground water changes, as do local features such as avulsions. Both banding and the formation of nodule-rich zones would be affected by geomorphology, *i.e.*, floodplain relief. Schumm (1968, 1977) assigned a major role in fluvial geomorphology to stabilization of floodplains by vegetation, which is strongly affected by climate. Results of local tectonism may eventually become clearly understood for the sites discussed in the remainder of this paper, allowing recognition of small scale climatic changes.

SITES OF THE SOUTHWEST

Paleocene and Eocene localities of southern North America will be considered in an effort to extract faunal and paleopedological clues concerning the factors controlling the faunal character of the south, in this section and the following one. Localities will be considered roughly in sequence from the west where data is moderately abundant to the east where it is very sparse. For a discussion of all North American Paleocene localities see Russell (1967). Figure 1 gives localities discussed in the following sections.

California

The only Paleocene mammalian remains from southern California constitute the Laudate faunule from the Goler Formation (Fig. 1, no. 1). The 2000-meter-thick Goler Formation has yielded only three identifiable mammal teeth. According to McKenna (1960) they belong to three species, only one of which can unquestionably be referred to a previously known genus. The faunule is possibly Torrejonian in age. According to McKenna (1960), the location of the Laudate faunule west of the Paleocene continental divide accounts for its containing two genera not known from further east and one which may have been present in California before its dispersal eastward.

Figure 4. An Eocene (Uintan) site in San Diego County, California. Students from San Diego State University collect fossil mammals from gray mudstone of the Mission Valley Formation. To the north, Jurassic rocks form highlands as they did in the Eocene.

West of the San Andreas fault system in San Diego County (Fig. 1, no. 5), red paleosols developed on Jurassic and Cretaceous rocks. They underlie Eocene mammal-bearing rocks, which have been intensively studied. They have been interpreted as laterites, probably Paleocene with a possibility that some may be late Cretaceous or early Eocene, by Peterson and Abbott (1975) and Abbott *et al.* (1976). These investigators consider the paleosols indicative of a humid tropical climate with greater than 120 cm annual rainfall, a climate warmer than the Eocene climate and the modern climate of the area. These paleosols certainly indicate a climatic difference from that under which the overlying Eocene rocks accumulated because the latter lack the striking red color. Movement on the San Andreas fault may have been as much as 200 km, so that climatic conclusions based on the laterite or on the overlying Eocene deposits must be considered as applying to lower latitudes in Mexico during the Paleocene.

Three areas of exposure of mammal-bearing terrestrial Eocene rocks are available from southern California. Exposures in San Diego County (Fig. 1, no. 4,5) are fluvial and alluvial fan coastal deposits intertonguing with marine rocks. These rocks have provided a rare opportunity for comparison of the terrestrial biostratigraphic chronology with the marine microfossil and megafossil subdivisions of the Eocene. Fluvial, alluvial fan, and lacustrine deposits of the Ventura Basin to the north filled an east-west trending trough (Golz, 1976, fig. 1). Recent work on the Eocene of southern California, including a salvage program in San Diego County under the direction of Jason A. Lilligraven, has produced a sequence of papers on these Uintan deposits (Fig. 4). Several authors have found evidence of endemism in Southern California Eocene faunas. Many species of Artiodactyls not known from deposits further east indicate the presence of geologic and ecologic barriers encouraging speciation according to Golz (1976). The far

smaller collection of San Diego County perissodactyls also shows some evidence of endemism (Schiebout, 1977). Black and Dawson (1965) considered small rodents and primates to indicate endemism, but small reptiles do not, according to Schatzinger (1975). Lillegraven's (1976) study of small insectivores suggested that a continuous forest cover was available from San Diego County eastward to sites in the Rocky Mountains and high plains. A possible explanation for endemism in some groups and not in others could lie in local climate, clues to which lie in the paleosols. Unlike the older underlying rocks, middle and late Eocene rocks of San Diego County lack red color but are rich in microcrystalline calcium carbonate nodules. Pierce and Peterson (1975, p. 75) postulated a change in climate from the older, hot, humid conditions (temperature 20-25°C, rainfall over 120 cm) to warm semiarid conditions (38-64 cm of rainfall) with a pronounced dry season. Some animals could have been confined to riparian forests and others could have ventured into drier interfluvial areas. Endemism seems most pronounced in those animals that would range beyond small forest belts. On the whole, the California Paleocene and Eocene data suggests that local microclimates and Laramide uplifts could have had major effects on early Tertiary mammal distributions.

Mexico

A fossil locality from Baja California (Fig. 1, no. 6) is the southernmost site yielding Paleocene mammals from North America. Like other sites lying west of the San Andreas Fault zone, it surely lay further south at the time of deposition. The locality has yielded a barylambdid pantodont, *Esthonyx,* and a primitive *Hyracotherium,* and is approximately Tiffanian in age (Morris, 1968; Ferrusquia, 1978).

Mexican Paleocene and Eocene paleosols east of the San Andreas Fault Zone give indications of the early Tertiary climate that are valuable for comparisons to the vertebrate-bearing localities lying in intermontane basins to the north. In the Late Cretaceous and Paleocene, the Parras and La Popa basins of northeast Mexico received approximately 6000 m of terrigenous sediment (McBride *et al.*, 1975, p. 1663). The delta plain sediments of the Upper Cretaceous-Paleocene Difunta Group in these basins are rich in red or reddish brown mudstones, which contain abundant soil-formed nodules. The red color is caused by post-depositional oxidation during dry seasons, induced by strong seasonal aridity, when the water table was low in an overall warm subhumid to semiarid climate (McBride *et al.*, 1975, p. 497). Caliche nodules are particularly common in coarse material topping upward-coarsening sequences interpreted as caused by gradual filling of lakes and swamps (McBride, 1975, p. 499-500). An Eocene vertebrate site in western Mexico at Guanajuato has yielded two rodents and a tapir forelimb from a site having red sediment (Fries *et al.*, 1955; Black and Stephens, 1973; Ferrusquia, 1978).

New Mexico

The concept of the Paleocene developed through studies of North American western intermontane deposits, and none played a greater role than those of the San Juan Basin in northwestern New Mexico and adjacent Colorado (Fig. 1, no. 9). The Puercan and Torrejonian Land Mammal Ages were originally defined on San Juan Basin mammal sites and faunas. Paleocene sites in the San Juan Basin number in the hundreds, and fossils from these localities are housed in many of the major museums of North America. Salvage work in the mainly fluvial Nacimiento Formation, made necessary by strip mining of coal contained in the underlying Cretaceous Kirtland and Fruitland Formations, can be expected to greatly increase our knowledge of Paleocene faunas in this area. Overbank mudstones of the Nacimiento (Fig. 5) and San Jose Formations show prominent color banding with bright red beds becoming more common upsection (Simpson, 1948, 1950). In the Nacimiento Formation red bands are rare in sediments bearing Puercan faunas but common in some sediments bearing Torrejonian fossils, while rare in others (Simpson, 1950). Soil-formed calcium carbonate nodules are locally common. According to Simpson (1948, p. 368-369), the banded mudstones of the upper portion of the San Jose Formation contain more red beds and are brighter in color, in general, than those of the lower San Jose Formation.

Figure 5. Two prominent red mudstone layers (arrow) at Barrel Springs, co-typical area for the Torrejonian Land Mammal Age of the Paleocene. Nacimiento Formation of the San Juan Basin.

Preliminary study of Eocene fossils of the San Jose Formation, which overlies the Nacimiento Formation in the San Juan Basin, fossils from the Galisteo Formation exposed in the Rio Grand Valley, (Fig. 1, no. 10) and fossils from the Baca Formation of central western New Mexico, (Fig. 1, no. 11) is underway. The San Jose Formation contains Wasatchian vertebrates (Simpson, 1948), and is currently yielding specimens from new sites (Lucas, 1977, pers. comm.). The Galisteo Formation has yielded a few fossils indicating a possible age range from Wasatchian to Duchesnean (Stearns, 1943; Robinson, 1957; Mellett, 1976). Stearns (1943) interpreted the color banding in the Galisteo Formation, including red bands, as formed in a warm climate with variable rainfall. The Baca Formation ranges in age from late Cretaceous to early Oligocene. Rocks containing Bridgerian fossils in the Baca Formation north of Datil are interbedded with red mudstone rich in soil-formed carbonate nodules. The Galisteo and the Baca Formation are both capped with volcanic rocks, recording the onset of local volcanism.

Texas

Work by John A. Wilson and colleagues in three areas of Trans-Pecos Texas has uncovered the southernmost large early Tertiary mammal faunas known from North America. The Vieja and the Agua Fria areas have yielded Eocene fossils; Big Bend National Park has yielded both Paleocene and Eocene sites. Work is in progress by Testamada on magnetic reversal chronology of the Trans-Pecos volcanic field (Wilson, 1978, pers. comm.).

Color banding and calcareous nodules characterize the overbank deposits of fluvial rocks of Maestrichtian to Wasatchian age in Big Bend National Park (Wilson, 1967; Schiebout, 1974; Lawson, 1972). Late Cretaceous and early Tertiary rocks in the park were subdivided by Maxwell *et al.* (1967) into the Javelina Formation, which contains Maestrichtian dinosaurs and pterosaurs (Lawson, 1972), the Black Peaks Formation, which contains Tiffanian to Clarkforkian mammalian faunas (Fig. 6; Schiebout, 1974), and the Hannold Hill Formation, which has yielded a Wasatchian fauna (Wilson, 1967). Some typically

Figure 6. Sinkhole in color banded fluvial mudstone of the Paleocene Black Peaks Formation. Microcrystalline calcium carbonate nodules are abundantly visible on eroded surfaces and in the scree in the foreground.

Torrejonian taxa are present in the Black Peaks Formation, but the Puercan faunas as found in the San Juan Basin are absent or at last have not been recovered. The Canoe Formation, which marks the beginning of local tectonic activity in the Big Bend region, contains a sparse, possibly Bridgerian, mammal fauna (Wilson, 1967). The Canoe Formation includes coarse conglomerates, unlike the underlying deposits.

Paleobotanical evidence substantiates climatic variability as partially responsible for the color banding in the late Cretaceous Paleocene and Eocene rocks in Big Bend National Park. Some Paleocene fossil wood from the Black Peaks Formation shows seasonal rings and some does not (M.L. Abbott, 1974, pers. comm.). Ripparian forests would not have suffered in dry periods as interfluvial ones would have. Lawson (1972, p. 71) studied a pollen flora of 37 species from one locality in Big Bend National Park, which he considered most closely contemporary to floras of the Paleocene Tullock and Lebo Formations, and concluded that it lived under a climatic regime of thermal equability and seasonal precipitation.

Eocene fossil-bearing sites in the Vieja area of west Texas (Fig. 1, no. 12) have received comprehensive treatment in a paper by Wilson (1977). The Vieja faunas have been published in several systematic works including Wilson (1971a, b; 1974, 1977), Wilson and Szalay (1976), Forsten (1971a,b), Harris (1967), McGrew (1971), Wood (1974) and Novacek (1976). Study of the Agua Fria region (Fig. 1, no. 13) by Wilson and others is under way.

The Vieja Group Uintan and Chadronian fossils occur in volcaniclastic rocks, and local volcanism was a major feature of the region. Temperatures were warm enough to make possible the presence of crocodiles in some braided streams; however, they were not abundant (Wilson, 1977). Harris (1967) and Wilson (1977) noted

the presence of caliche in Chadronian (early Oligocene) beds at Ash Spring and postulated a gradual drying trend for the Eocene and Oligocene Vieja Group as a whole.

A single mammal mandible, which has been recovered from the mid-Eocene Cook Mountain Formation at Lake Casa Blanca in Laredo, Webb County, Texas (Fig. 1, no. 15), is under study by John A. Wilson. He identifies it as belonging to *Leptoreodon* cf. *marshi* (Wilson, 1978, pers. comm.).

The prominent color banding seen in the early Tertiary deposits of New Mexico and Big Bend National Park, Texas, is not widespread in Wyoming until the early Eocene. Climatic change is likely to have played a major role in triggering changes from drab to red banded beds. Red color and carbonate nodules of the Willwood Formation are a good example. Neasham and Vondra (1972) and Bown (1977) attributed the red banding of fluvial overbank facies of the mid-basin region to fluctuation of the water table. Red layers are described as produced in interfluvial areas where sedimentation rates were low in a warm, humid climate with periodic dry seasons (Neasham and Vondra, 1972, p. 2178-2179). Red banding is also prominent in the Indian Meadows Formation (probably Wasatchian) and in some Eocene rocks of the Green River Basin (Picard and High, 1968). On the other hand, Braunagel and Stanley (1977) described Eocene variegated redbeds in the Cathedral Bluffs Tongue of the Wasatch Formation in Wyoming that were controlled mainly by local depositional events, rather than post-depositional conditions. According to Braunagel and Stanley (1977), upward-fining couplets of green iron-poor siltstone overlain by red claystone represent individual floods on an alluvial plain near a lake. According to Dorr and Gingerich (1978, pers. comm.) the boundary between drab beds and variegated redbeds in the Chappo Member of the Wasatch Formation is sharply time-transgressive in the Fossil Basin of Wyoming. Redbeds first appear in the middle Tiffanian in the Fossil Basin; in the Hoback and Bighorn Basins they first appear in the Clarkforkian (Dorr, 1978, pers. comm.). When color banding is water-table-controlled both local basinal conditions and climate will be important in determining the color of overbank mudstones.

THE SOUTHEAST

The southeast, here defined as beginning in eastern Texas, is considered as a unit (Fig. 7). Accidental discovery has played a major role in early Tertiary vertebrate finds in southeastern North America; therefore, terrestrial vertebrate finds and terrestrial environmental studies are rare at the moment. The only Paleocene terrestrial vertebrate find known from the southeast is the facial and palatal part of a small skull, on the basis of which Simpson (1932) named *Anisonchus fortunatus*. The specimen was recovered from a well core in Caddo Parish, Louisiana (Fig. 1, no. 16) from an approximate depth of 750 m (Simpson, 1932). Few Eocene mammals have been reported from the southeast in the literature. One of these is a titanothere from the Lisbon Formation of Clark County, Mississippi (Fig. 1, no. 17; Gazin and Sullivan, 1942). These authors named *Notiotitanops mississippiensis* on the basis of this specimen. One molar of the tillodont *Anchippus*, possibly Bridgerian, was recovered from the Shark River marine marl of New Jersey (Gazin, 1953). A single miacid tooth has been recovered from the base of the Gosport Sand, which overlies the Lisbon Formation at the Little Stave Creek site in Clark County, Alabama (Fig. 1, no. 18; J. Thurmond, 1977, pers. comm.). A fauna of marine and terrestrial animals has been recovered from upper Eocene estuarine sediments of the Twiggs Clay in Georgia (Fig. 1, no. 19). The snake fauna indicates semitropical or tropical conditions (Holman, 1977). A terrestrial mammal fauna from this site is under study by M. Voorhies (Voorhies, 1978, pers. comm.).

Palynological data on the paleoclimate of the Paleocene and Eocene of the Gulf Coast indicates the presence of temperate as well as subtropical elements (Gray, 1960; Jones, 1961; Elsik, 1965; Nichols and Traverse, 1969; Fredericksen, 1973). The possibility exists that the Eocene temperate elements are really part of upland floras, perhaps from as far away as the Appalachians, admixed with coastal plain floras (Nichols and Traverse, 1969). Graham (1972) considered temperate plant communities of the eastern escarpment of the Mexican plateau, some members of which are present in the Eocene of the Mississippi Embayment, to have moved progressively

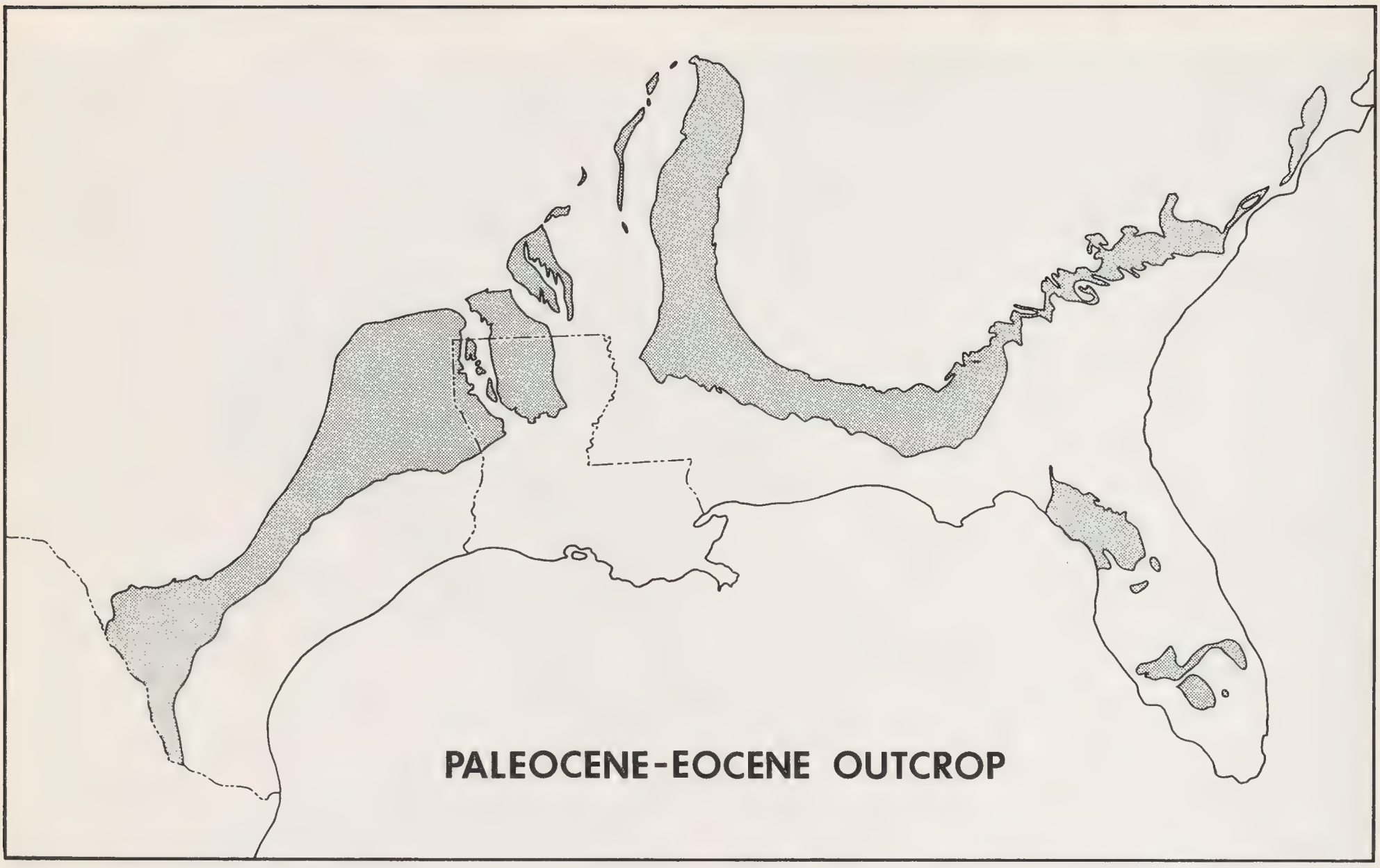

Figure 7. Paleocene and Eocene rocks of the southeast.

southward to reach Mexico in the Miocene. The work of Dilcher (1973) on less readily transportable plant megafossils from the middle Eocene of Kentucky and Tennessee indicates that some of the temperate elements were part of the coastal plain flora. Foliar physiognomy of floras from clay pits dug in Eocene abandoned channel deposits, including leaf margin and leaf size analysis, indicates a temperature regime of equable warm-temperate to cool-subtropical, and a moisture regime of seasonably dry to slightly moist (Dilcher, 1973). Dilcher (1973) also reported wood with growth rings indicating seasonal fluctuations. Wolfe (1978), also working on foliar physiognomy, postulated a cooling trend from early Paleocene Tropical Rain Forest conditions in north Louisiana to late Paleocene Paratropical Rain Forest conditions, followed by an early Eocene warming trend in the Mississippi Embayment. The middle Eocene floras studied by Dilcher (1973) are considered to be dry subtropical by Wolfe (1978). These floras indicate a pronounced drying trend from Paleocene to middle Eocene in the Mississippi Embayment (Wolfe, 1978). This Eocene drying trend seen on the southern coastal plain supports the idea that the warmth and at least seasonal dryness reflected in soil-forming processes in the Eocene of northern intermontane basins, such as those in Wyoming, was due in part to mid-continent-wide climatic changes.

Less is known of early Tertiary paleopedology for the southeast than is known for the southwest. In a discussion of the origin of bauxite, Harder (1949) described scattered bauxite deposits of Paleocene and Eocene age, which occur in a belt along the east side of the Mississippi Embayment from southwestern Georgia to central Arkansas, and concluded that a warm, humid climate with alternating wet and dry seasons favored the formation of such bauxites.

Hope for future finds of southeastern mammals is greatly increased by the prospect of lignite mining in the Paleocene and Eocene rocks exposed along the west side of the Mississippi Embayment. Strip mining will produce extensive outcrops where soil cover had previously prevented paleontological work. Tens of thousands of acres are already leased preparatory to mining

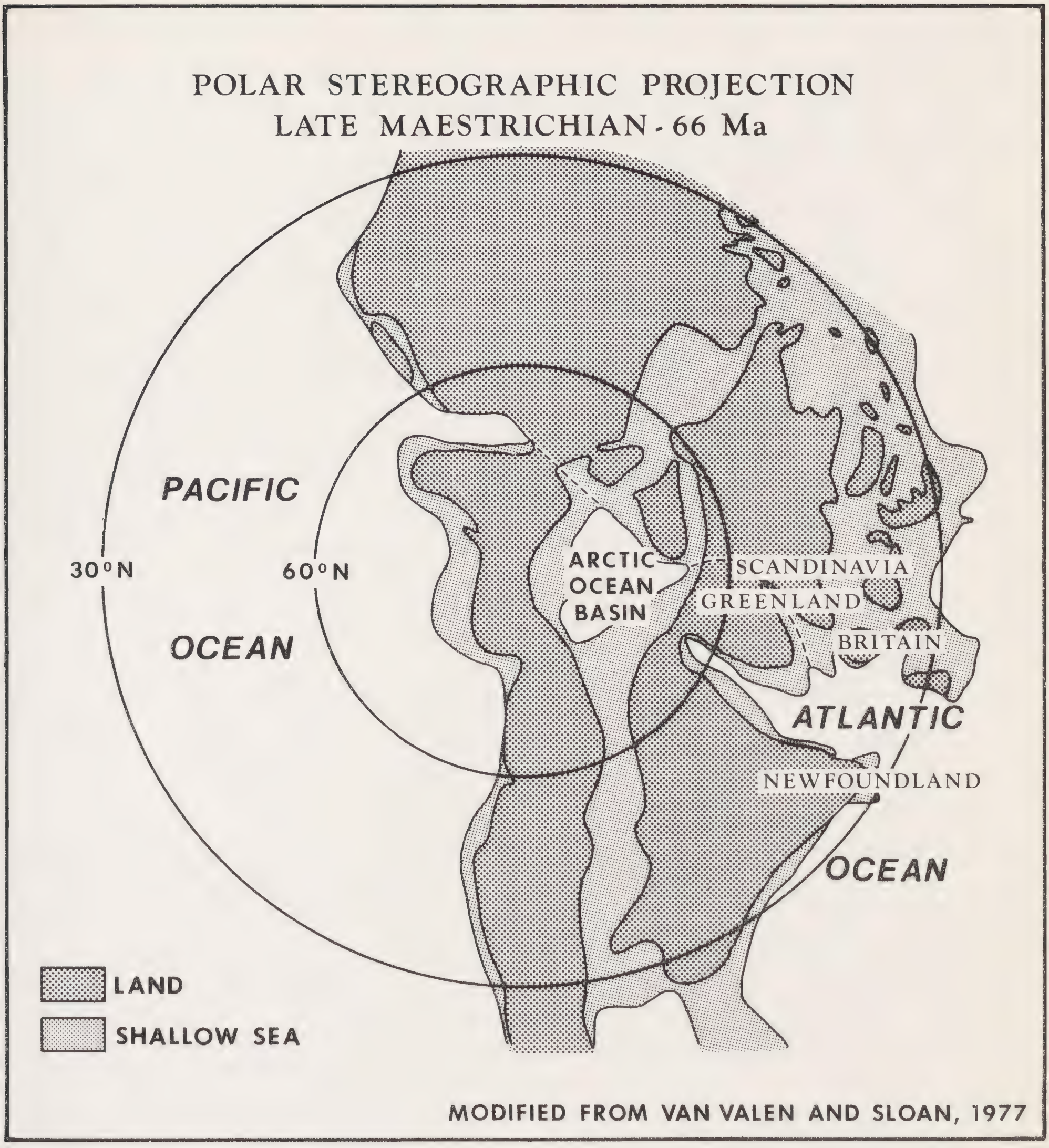

Figure 8. Late Cretaceous distribution of land and sea for the northern hemisphere.

in east Texas, Louisiana and Arkansas. The pace and scale of this mining is likely to surpass anything seen up to the present time in east Texas. A test mine started in the spring of 1978 excavated Eocene lignite in Red River Parish, Louisiana. There is a possibility of recovering Paleocene as well as Eocene mammals from Louisiana. Murray (1948) named three Paleocene formations cropping out in northwest Louisiana the Naborton, Logansport and Hall Summit formations. Each contains fluvial, deltaic and lignite deposits (Murray, 1948, p. 88-134).

DISCUSSION

Recognition of early Tertiary geographic features (Fig. 8) and faunal and floral migration patterns make possible some predictions regarding the future paleontologic and paleoecologic role of the terrestrial

early Tertiary deposits of the Gulf Coast. Increased exposure of Gulf Coast early Tertiary sediments by strip mining may provide opportunity to test these predictions in the near future.

Clues to the affinities of southeast faunas can be provided by paleoclimatic data. The Tiffanian faunas of the Big Bend region of Texas show far less similarity to French Paleocene assemblages than the high degree of similarity of the Wasatchian faunas of the northern intermontane basins to the Wasatchian of Europe would lead one to expect. If continental drift is considered to have disrupted the North American-Europe migration route in the middle Eocene (Dawson *et al.*, 1976), this route should be expected to have been useable in the Paleocene and early Eocene. Evidence exists, however, for climate and vegetational shifts, particularly a northward shift of the subtropics in the earliest Eocene, which would make high latitude intercontinental routes particularly attractice in the early Eocene (Sloan, 1969; Hickey, 1977; Wolfe, 1978). The early Eocene similarities suggest that mere distance, for example, between Wyoming and Europe, was not a major barrier. An interior seaway linked with the Gulf of Mexico in roughly the same position as the Cretaceous interior seaway existed in the early Tiffanian (McGrew, 1963; Sloan, 1969; Fox and Olsson, 1969, Van Valen and Sloan, 1977). Lilligraven (1969) considered the Cretaceous seaway an important factor affecting marsupial and eutherian distribution. Krause and Baird (1979) discussed very fragmentary mammal specimens from east Texas and New Jersey, which establish the presence of therian and nontherian mammals in North America, east of the seaway in the Late Cretaceous. The Paleocene seaway would have had major effects on climate and base level as well as geographic effects as a barrier. These effects may have lingered after its withdrawal.

The isolating effects of highlands are probably partially responsible for endemism in California in the Paleocene (Mc Kenna, 1960) and Eocene (Golz, 1976), and in west Texas (Schiebout, 1974), which may have been affected by a Tiffanian shift of the continental divide (Sloan, 1977, pers. comm.). Eventually the effect of highlands versus the effect of a seaway may be analysed when mammal faunas of the southeast are recovered. The lack of local highlands along the Gulf Coast should allow a much freer interchange of animals more like the situation noted by Wilson (1956) for the Miocene of the Gulf Coast than that seen in the intermontane basins.

It is likely that the southeast of North America belonged to a faunal province distinct from the better-known deposits of western North America in the Paleocene. It can be anticipated that Paleocene faunas east of central Texas would have strong European affinities and that the faunas from the late Eocene east of central Texas would show stronger affinities to those of the classic western North American faunas of the intermontane basins than to European assemblages. A long route across northern areas with distinctly different climate, or a long passage including a seaway barrier, separated the southwestern Paleocene faunas such as those from Big Bend National Park, Texas, from those of Europe. Influxes of animals into northern intermontane basins such as those in Wyoming have been interpreted as northward shifts of populations originating in subtropical or tropical environments (Sloan, 1969). The North American southeast is often ignored as a possible source of immigrants and a region in which new forms may have been developing, although Wood (1977) considered it the most likely area of origin for the Rodentia. The southeast, as well as Mexico or even Central America, must be considered as a source region for immigrants.

Other generalizations about the significance of southern faunas yet to be found can be made. Southern regions can be expected to have had overall more stable environmental conditions and, therefore, a greater faunal diversity and a higher number of animal specialists then northern regions. Both marine and terrestrial faunas show this trend (Bretsky and Lorenz, 1970; J. W. Wilson, 1974). Some biostratigraphic zones, useful in the north, will not be recognizable in the south. Differing characterizations for northern and southern areas will be required for some Paleocene zones. For example, a zonation defined on pantodonts,

the most common large herbivore in the west Texas Paleocene (Schiebout, 1974), or periptychids would prove more useful in Texas and probably also in areas further south, than one based on primates, such as the elegant zonations produced by Gingerich (1976) and Rose (1977) from work in Wyoming.

Soil forming processes produce diagenic alterations that are useful to the terrestrial early Tertiary paleoecologist in understanding the conditions under which deposits formed. Calcareous nodules form today in the B horizon of pedocal soils in regions where rainfall is sufficient to remove calcium from the A horizon by leaching, but not enough to wash carbonates out of the soil zones. Temperature determines the effectiveness of rainfall, because it controls evaporation (Pierce and Peterson, 1975). Nodular layers appear to form in the part of the soil where the water table fluctuates because of seasonal aridity. Red layers found in banded overbank deposits require an environment in which inherited iron oxide or iron oxide-bearing minerals are altered further by oxidation (Van Houten, 1973). Nodules may occur in gray sediments, as in the California coastal Eocene, or in both red and gray beds, which are in intimate association as seen in the west Texas Paleocene. In the west Texas Paleocene beds the nodules and nodular layers are best developed in the reddest beds, suggesting that intensification of one or several of the nodule-producing factors triggers the production of red coloration. The Eocene Sespe Formation of inland California contains variegated beds in contrast to the slightly younger coastal formations, so the controlling factor may be the lower temperature and/or the higher rainfall near the coast. Small climatic changes through time may be responsible. Peterson and Abbott (1975) postulated a cooler depositional temperature for coastal Eocene beds of California than for the underlying red sediments.

Changes in the level and stability of the water table, which appear responsible for the color banding, indicate considerable variability with time in the floodplain environment. Identical overbank deposits assume a very different appearance if the post-depositional water tables lie at or above the floodplain surface than if interfluvial areas are well-drained. Height of the water table would also have considerable affect on flora and fauna. The time necessary to form pedological features such as nodule layers also provides a clue to details of rates of deposition.

Paleopedological data in the early Tertiary of North America does reflect large scale climatic shifts such as the northward shift of subtropical climate at the beginning of the Eocene. Changes in the water table, which produce the striking color banding of red, gray and black in many fluvial deposits, may indicate widespread climatic changes or smaller shifts of greater than seasonal duration. Soil-formed features such as thick color bands are often more widespread than any fluvial facies and usually, being water-table-controlled, they represent synchronous surfaces that had little original relief. Color bands have long been used informally as stratigraphic markers. For example, prominent black beds were useful in tying together localities in the west Texas Paleocene (Schiebout, 1970). If local effects, caused by changes in the positioning of major channels and accompanying changes in sediment supply, can be separated from the effects of climatic patterns, a powerful stratigraphic tool would result, allowing correlation beyond single outcrop areas. Soils have begun to be used as stratigraphic markers as well as climate indicators. For example, Ortlam (1971), working in the Triassic and Permian of Germany, traced red-violet layers to produce correlations useful over all of southern Germany. Buurman (1975) has collected data on a variety of uses being made of paleopedology.

Accurate notation of mudstone color and the presence and type of nodules by workers in the early Tertiary continental deposits can produce a great deal of information valuable to the paleoecologist, phylogeneticist, and stratigrapher. Vertebrate paleontologists should be sure to record such data for their localities and stratigraphic sections. Workers in the terrestrial Paleocene and Eocene should become as alert to paleopedological features as workers in the terrestrial Pleistocene are.

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A STUDY OF THE UPPER EOCENE OTOLITHS OF THE YAZOO CLAY IN CALDWELL PARISH, LOUISIANA

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ABSTRACT

An extensive and detailed study of the otoliths from three localities of the Tullos Member of the Yazoo Clay in Caldwell Parish, was undertaken in order to classify and describe the upper Eocene otoliths. The classification of the otoliths was based mainly on Recent forms when extant genera were available for comparison. Eleven families and sixteen genera were identified and described through a systematic study of approximately 1600 otoliths from the Tullos Member of the Yazoo Clay.

LOCATION OF STUDY AREA AND COLLECTION PROCEDURES

The study area is located in the southeastern portion of Caldwell Parish, Louisiana, approximately in the central part of northern Louisiana. The study area is bounded by the Ouachita River on the east, by the Caldwell-Catahoula Parish boundary on the south, by Louisiana State Highway 126 on the west, and by the community of Copenhagen on the north. Although collections were made at many exposures of the Yazoo Clay in the study area, only three exposures were selected for study. The three localities were chosen because they were stratigraphically equal, extensive, and yielded the most vertebrate material.

Collection procedures for this study included unit volume collections and extensive surface collections over a four year period. Unit volume samples were processed in an ultrasonic cleaner using tap water (no additives or cleaning solutions). The samples were wet-sieved through a U.S. Standard No. 40 sieve (opening-420 microns), and all material that was retained in the sieve was kept for study.

ACKNOWLEDGMENTS

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STRATIGRAPHY

All otolith specimens in this study were collected from the Tullos Member of the Yazoo Clay (Jackson Group). Otoliths were collected from essentially the same stratigraphic horizon at all three localities. Specimens from Locality I were collected approximately 20 feet (6 meters) to 80 feet (24 meters) above the Moodys Branch-Yazoo Clay contact. Specimens from Locality II and III were approximately 50 feet (15 meters) to 90 feet (27 meters) above the Moodys Branch-Yazoo Clay contact. The specimens from Locality I were collected mainly from the lower strata of the Tullos Member, while specimens from Locality III were collected from the upper portion of the Tullos Member.

PHYSIOLOGY OF THE OTOLITHS AND RELATED STRUCTURES

A majority of vertebrate remains can be classified as parts of or related to the skeletal system. Various bones, spines, vertebrae, teeth, and scales are common vertebrate fossils that represent parts of the skeletal system. Otoliths are unique in that they are not parts of the skeletal system, but integral and specialized parts of the acoustico-lateralis system.

Otoliths are located in the two auditory labyrinths of the teleost fish. The deeply buried labyrinths are located posterior to the brain and anterior to the first vertebra in the skull of the fish. The location of the labyrinth and its relation to other structures in the braincase is shown in Figure 1.

The utriculus, sacculus, and lagena represent cavities in the labyrinth (Figure 2).

In each of these cavities, there is a single "stone" or body composed of calcium carbonate. These are the "earstones" known as otoliths or statoliths, which are secreted by the walls of the labyrinth (Norman 1931). The otoliths increase in size by the deposition of calcium carbonate in layers on the outer surface. Yapp (1965), as well as many other workers, states that otoliths show annual growth lines. These lines are visible under the microscope as alternating light and dark concentric rings, which are a result of the varying rates at which the calcium carbonate was secreted and probably corresponds with various seasons.

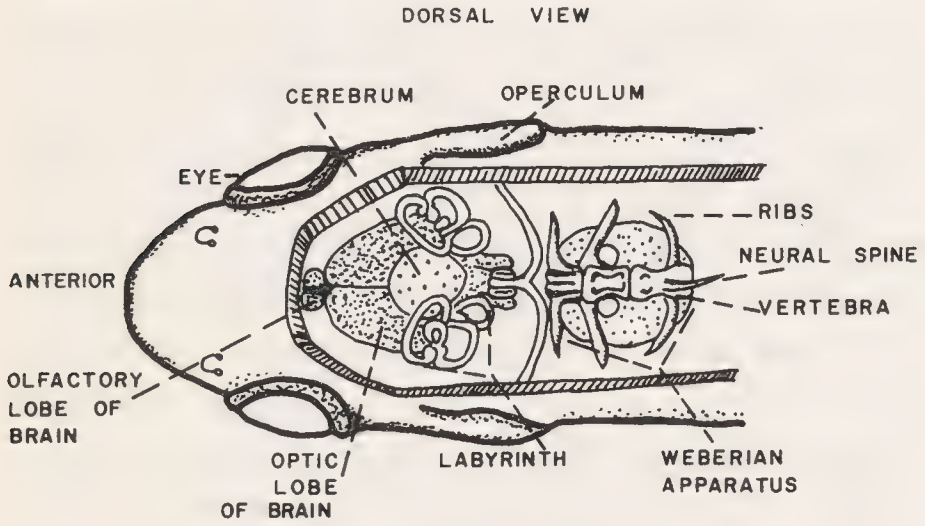

FIGURE 1. Location of the labyrinth and related structures.

The otoliths in each cavity of the labyrinth are given a name. The sacculus contains the sagitta, the lagena contains the asteriscus, and the utriculus contains the lapillus. Thus, there are three otoliths in each labyrinth and six otoliths for each fish.

According to Lowenstein (1957), the labyrinth has four chief functions. The labyrinth is concerned with the maintenance and regulation of muscle tone and is a receptor for angular accelerations, gravity, and sound. Many of these functions are related to one another. Norman (1931) emphasized that the purpose of the labyrinth was mainly to maintain equilibrium and to perceive sound. Lagler *et al.* (1962) stated that the labyrinth and its associated structures maintain the equilibrium and orientation of the fish, receive vibrations, and perceive sound frequencies.

MORPHOLOGY OF THE OTOLITHS

The bony fishes usually contain three otoliths or statoliths in each labyrinth. Koken (1884) originally named the otoliths as the sagitta, lapillus, and the asteriscus. These names were based on their shape in the carps: sagitta (an arrow), lapillus (a stone), and asteriscus (a parenthesis sign). As discussed earlier, these otoliths are located in the sacculus, utriculus, and the lagena, respectively. Sagitta, lapillus, and asteriscus are used by many workers: Dante (1953), Frizzell (1965), Frizzell and Lamber (1961), and Frizzell and Dante (1965). Some workers use the terms sacculith, utriculith, and lagenalith. These terms relate the otoliths to their sites within the labyrinth and are considered to be more descriptive than the terms of Koken (Stinton 1975).

The sagitta is the largest of the three otoliths found in the bony fishes with the lapillus and the asteriscus being much smaller. However, one exception to this is the Order Ostariophysi. In the ostariophysians, the sagitta is the smallest with the lapillus and the asteriscus being larger. In most ostariophysians, the asteriscus is the largest. One exception that occurs in the ostariophysians is the Family Ariidae. In the Ariidae, the lapillus is very large and can be useful in identification.

In most studies, the sagittae are examined because of the characteristic pattern that is found on the inner face. This pattern is indicative of genus and species. Different species of a genus can be discerned by small differences in the sagittae. The sulcus usually remains the same in the different species within a genus. Specific differences are usually found on the periphery of the sagittae, especially the anterodorsal area (Stinton 1975).

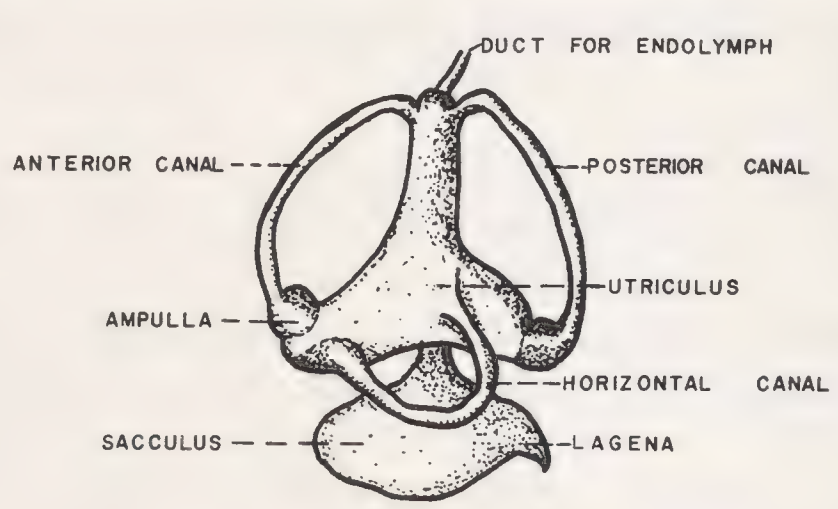

FIGURE 2. Structures of the labyrinth.

Morphologic features of the inner face of the sagitta are shown in Figure 3. The inner face is the side that is connected to nerve endings and usually has a characteristic pattern on it. The terms in Figure 3 are fairly standard in otolith studies and are the terms used by Frizzell and Dante (1965).

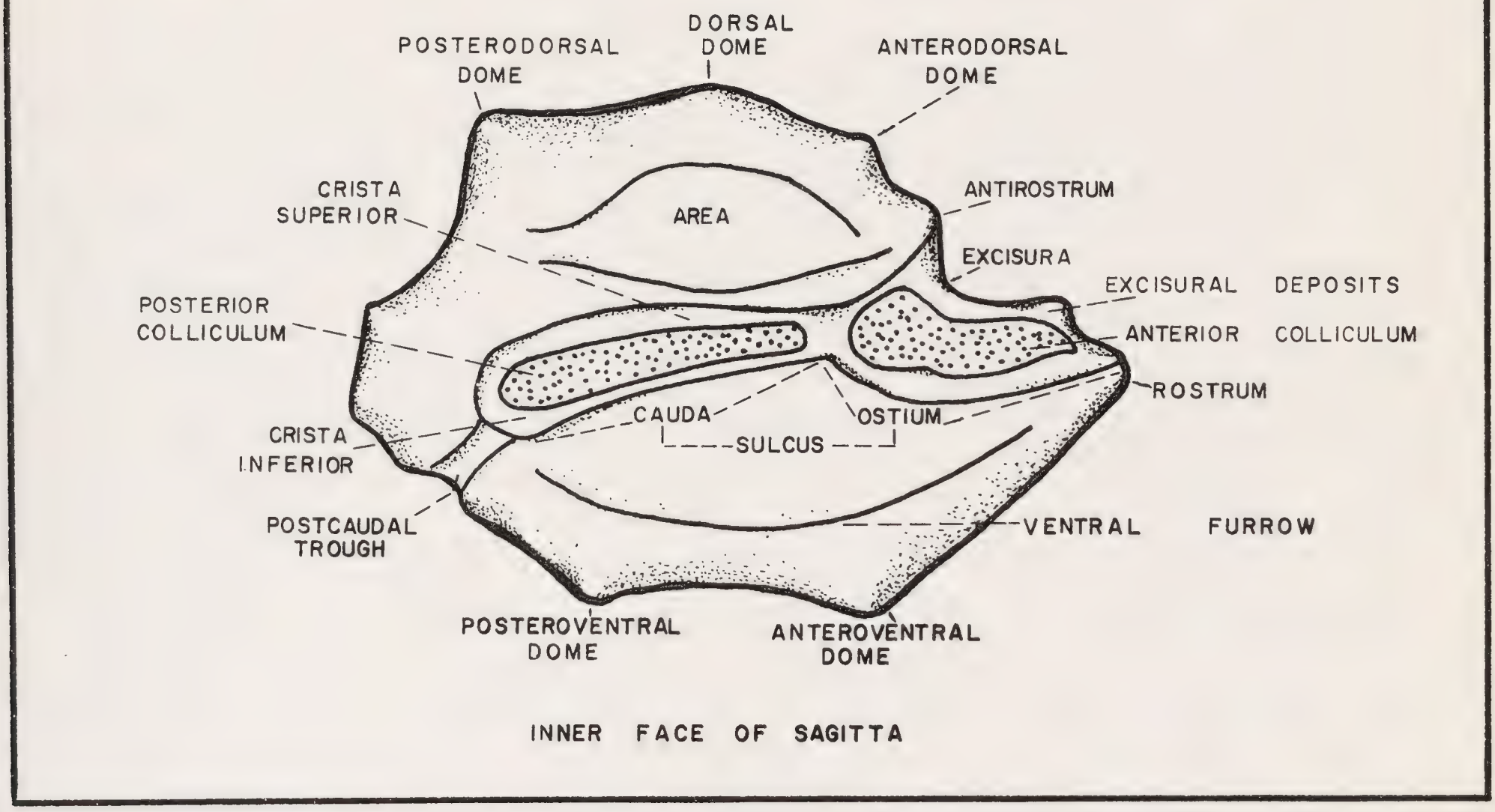

FIGURE 3. Morphologic features of the inner face.

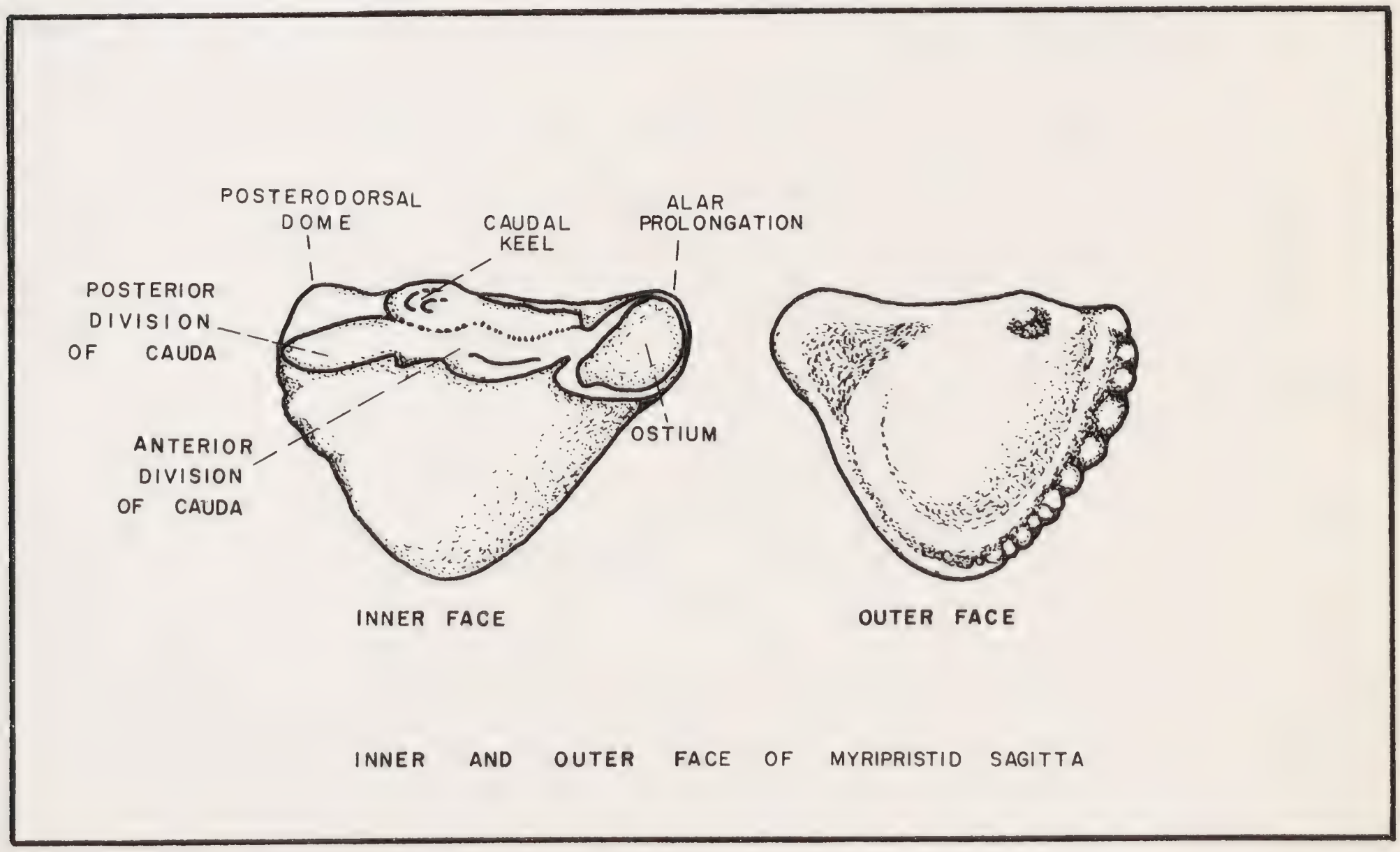

FIGURE 4. Morphologic features of the myripristid sagitta.

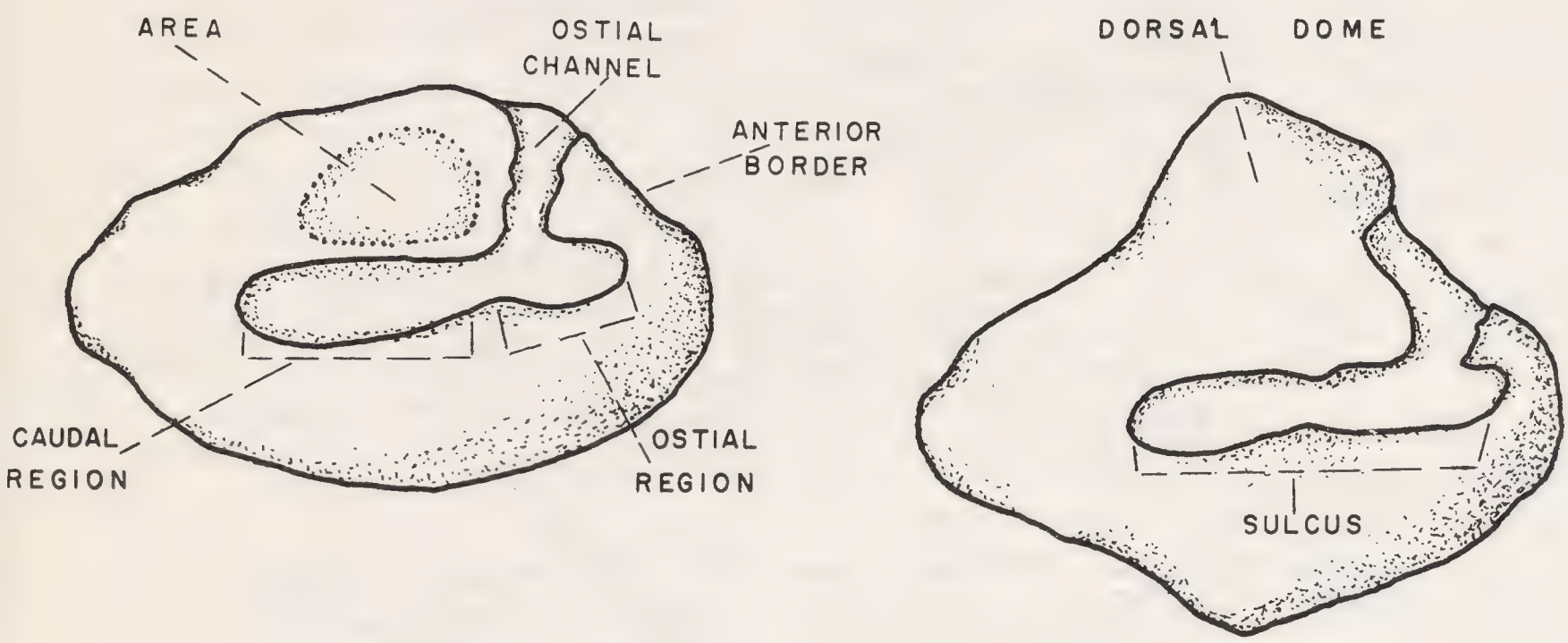

FIGURE 5. Morphologic features of the congrid type sagitta.

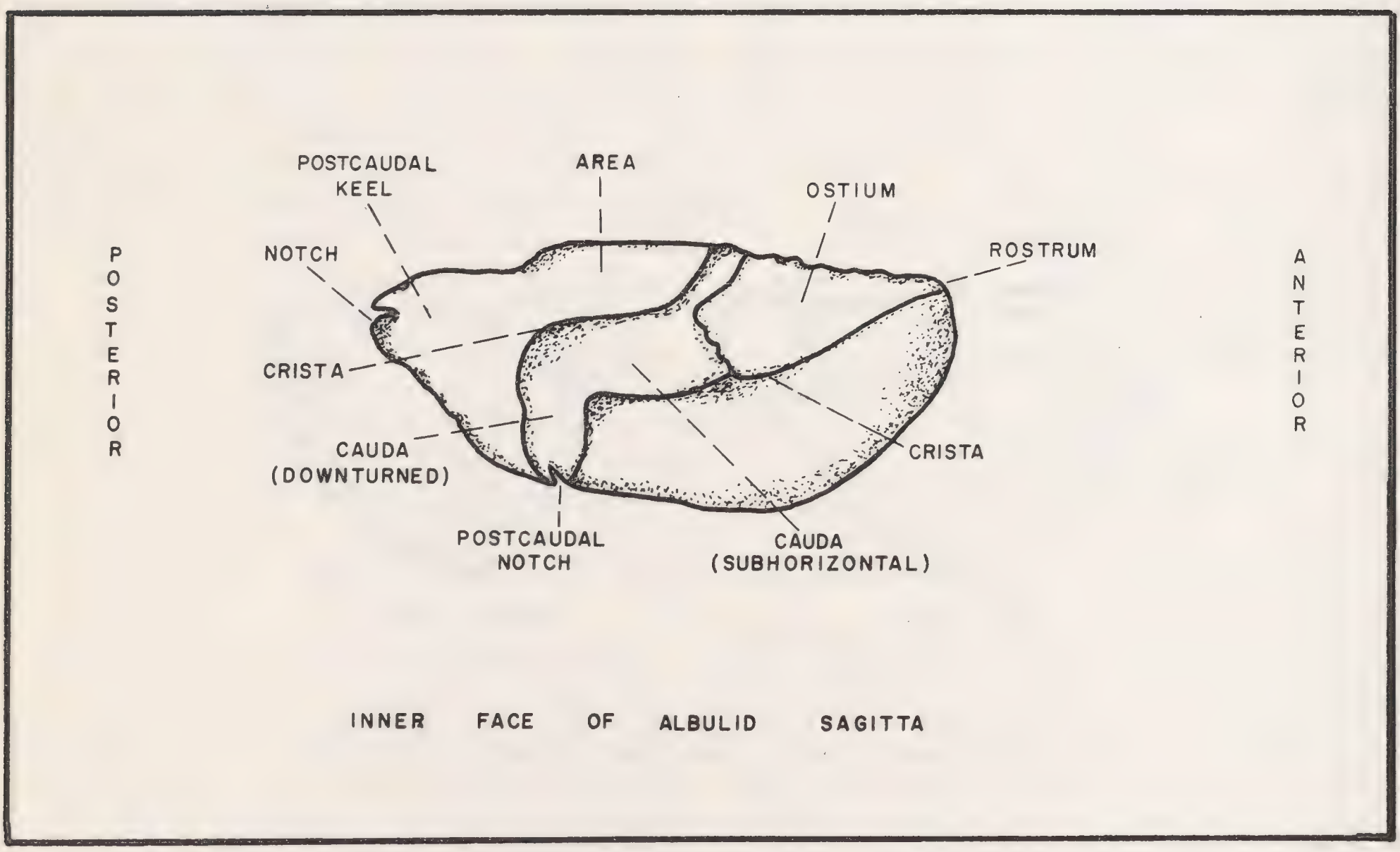

FIGURE 6. Morphologic features of the albulid type sagitta.

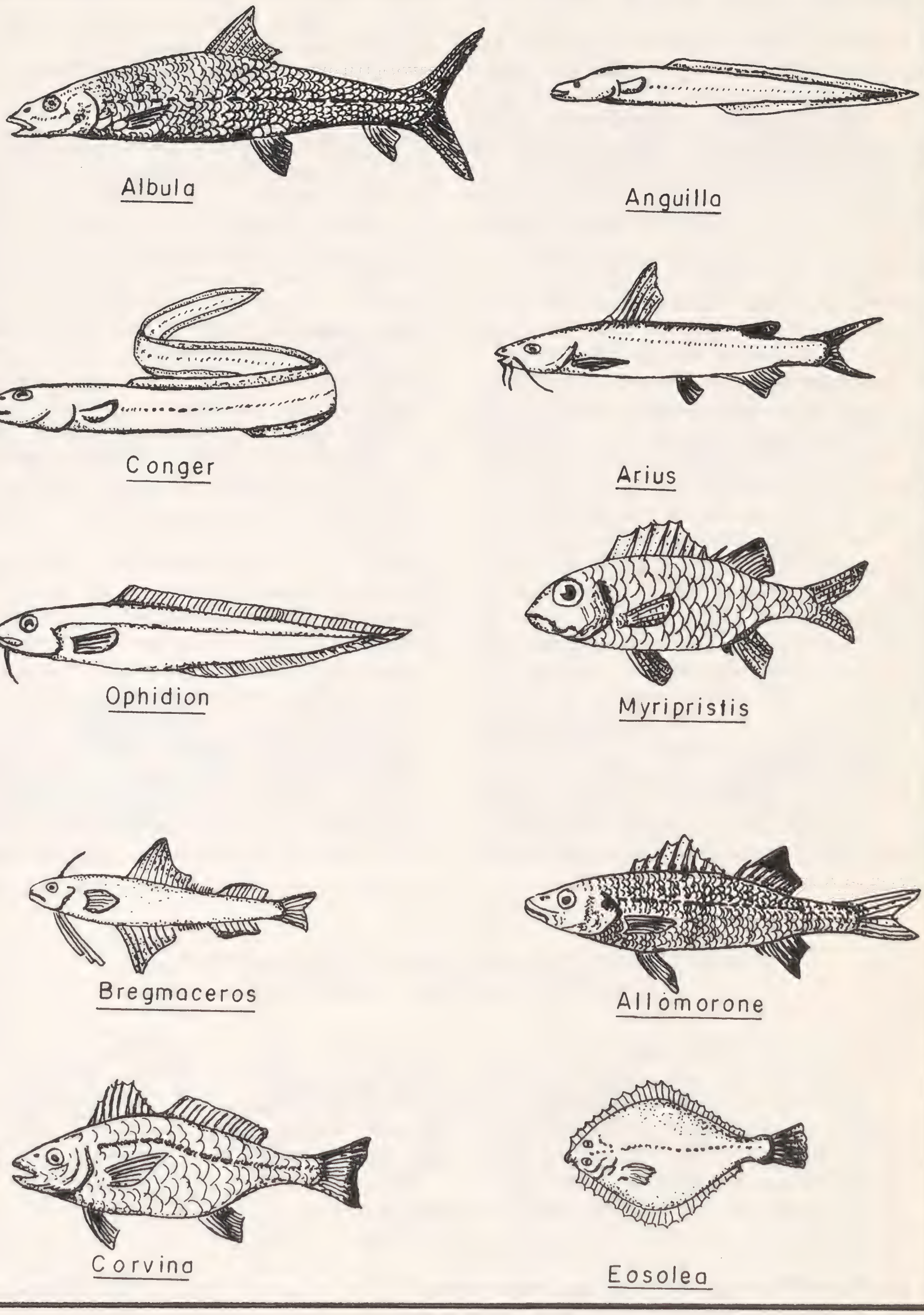

FIGURE 7. Genera of fish present in study area based on otoliths.

The most obvious feature on the inner face of the sagitta is the sulcus (Figure 3). In many sagittae, the sulcus is divided into the cauda and the ostium with the collum between the two. Other features are probably best described by referring to the margins of the sagittae. The dorsal, anterior, ventral, and posterior margins can be recognized on the sagitta, but their exact boundaries are difficult to define. Projections from the periphery are named according to the margin on which they are located. A dome located on the dorsal margin would be referred to as the dorsal dome. Other domes would be referred to as anterodorsal dome, anteroventral dome, posteroventral dome, and posterodorsal dome. Prominent projections on the anterior of the sagitta are the rostrum and antirostrum. The excisura and excisural deposits can also be found on the anterior margin. Colliculum deposits in the cauda and ostium are referred to as the posterior colliculum and the anterior colliculum, respectively. The crista superior rims the cauda dorsally and the crista inferior rims the cauda ventrally. Many sagittae have an area in the dorsal region above the crista superior. A ventral furrow may be located below the sulcus.

The terms shown in Figure 3 are general terms and may not be totally adequate for a description of a sagitta. Frizzell and Dante (1965) suggested that separate illustrated terms be used for each family of fishes. These authors identified special characteristics of the myripristid, congrid, and albulid sagittae (Figures 4, 5, and 6).

TAXONOMY

The ideal system of taxonomy would be one in which the otoliths are placed in families, genera, and species, but this is not always possible. Fossil otoliths should be assigned to living representatives when possible. This, however, requires excellent Recent comparative material as well as fossil material. There is also the problem of extinct genera and species. Some otoliths represent extinct forms and may not have living representatives.

When Koken (1884) studied the otoliths, he was forced to create his own system of nomenclature. Koken assigned all otolith specimens to the genus *Otolithus*. Then in parenthesis, Koken added the name of the genus, or of the family in the genitive plural, followed by the species name. For example, Koken identified one otolith as *Otolithus (Sciaenidarum) intermedius*. However, as the otoliths were more carefully studied and evolutionary sequences were determined, the *Otolithus* nomenclature was dropped. Today, *Otolithus (Sciaenidarum) intermedius* is known as *Corvina intermedia* (Family Sciaenidae). The genus *Corvina* is extant and comparative material is available. Unfortunately,

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PLATE 1

CHARACTERISTIC OTOLITHS IN THE YAZOO CLAY, CALDWELL PARISH, LOUISIANA

Figure

1. *Albula* sp., right sagitta, inner face
2. *Anguilla*? sp., left sagitta, inner face
3. *"Conger" dissimilis*, left sagitta, inner face
4. *Ariosoma* sp., left sagitta, inner face
5. *Conger? vetustus*, left sagitta, inner face
6. *Arius* sp., left lapillus, outer face
7. *Bregmaceros troelli*?, right sagitta, inner face
8. *Preophidion stintoni*, right sagitta, inner face
9. *Ophidion*? sp., left sagitta, inner face
10. *Brazosiella* sp., left sagitta, inner face
11. *Myripristis creola*, left sagitta, inner face
12. *Allomorone* sp., left sagitta, inner face
13. *Corvina intermedia*, left sagitta, inner face
14. *Ekokenia* sp., left sagitta, inner face
15. *Jefitchia claybornensis*, left sagitta, inner face
16. *Eosolea texana*, left sagitta, inner face

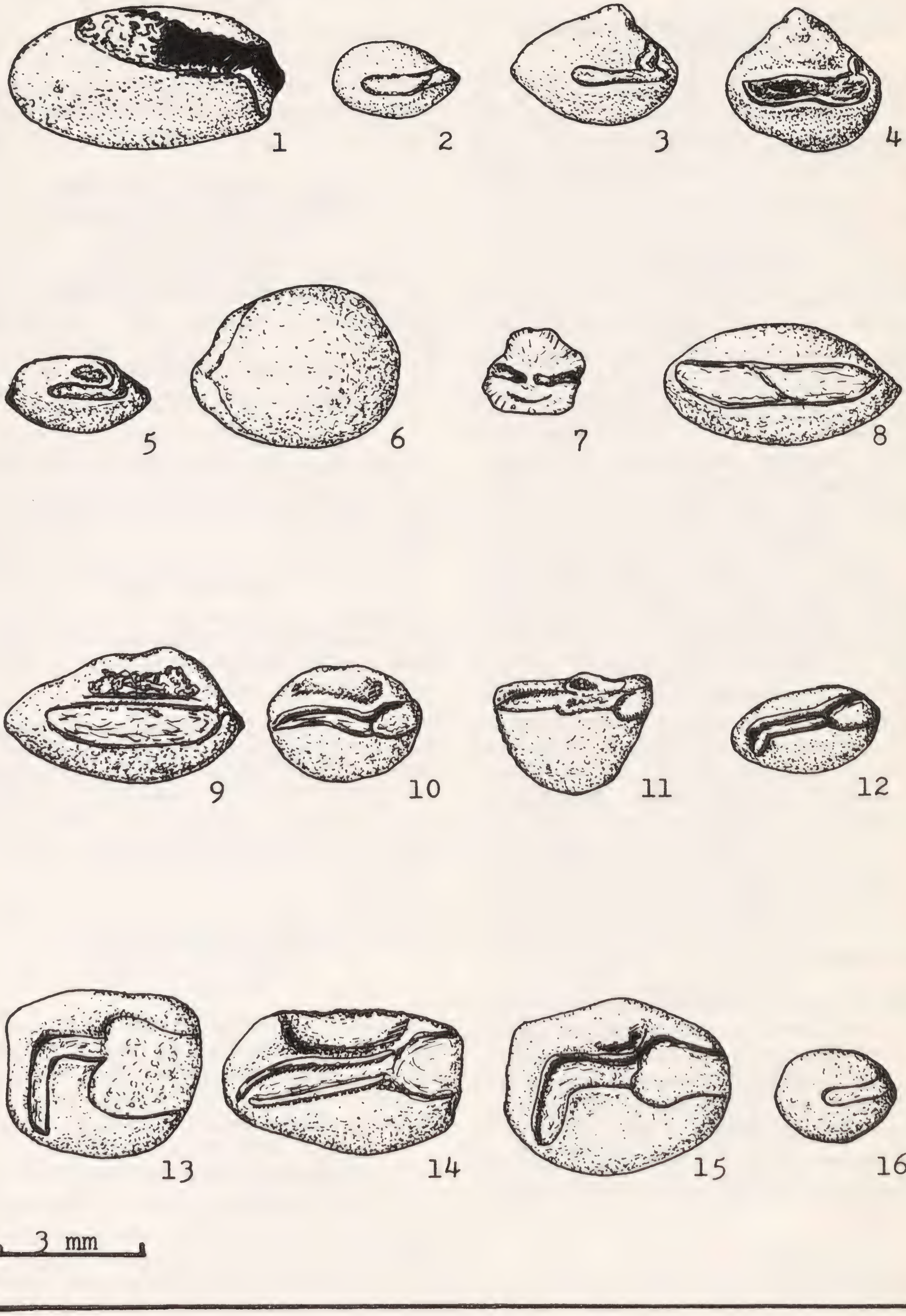

PLATE 1

all otoliths do not have extant representatives.

SYSTEMATIC PALEONTOLOGY OF THE OTOLITHS

The classification of fossil otoliths, or statoliths, is still in its initial stages. Although attempts have been made to classify otoliths for over a hundred years, it has been in the last twenty years or so that otolith classification has begun to develop into a system of classification in which phylogenetic relationships are understood. It is unfortunate that many early taxonomists failed to search for ancestor-descendant relationships. However, workers have become acutely aware of the necessity of searching for Recent representatives of fossil otoliths. As more fossil otoliths are collected, studied, and compared to possible descendants, a more complete understanding of the phylogeny of the fishes, based on otoliths, will be obtained. Many recent workers, such as Fitch, Nolf, Frizzell, Stinton, Lamber, and Dante, have diligently searched in order to ascertain phylogenetic relationships.

The systematic paleontology in this study was based mainly on Romer (1966). Romer's classification was utilized because it was fairly recent, complete, and familiar to many paleontologists and biologists. Below each classification, a diagnosis is given on each species. The diagnosis presents a brief statement of the unique, discriminating characteristics of that specific otolith. The diagnosis is by no means a complete description. All of the otoliths are figured in Plate 1.

Based on the identification of the otoliths, line drawings were prepared for some of the genera found in the study area. These drawings were based on Recent genera or very similar Recent genera. Figure 7 shows some of the genera that were present in the study area based on otoliths and comparisons with extant genera.

SYSTEMATIC PALEONTOLOGY

Kingdom ANIMALIA
Phylum CHORDATA
Class OSTEICHTHYES
Infraclass TELEOSTI

Order ELOPIFORMES
Family ALBULIDAE
ALBULA sp.

Diagnosis — *Albula* sp. is characterized by a long ostium, a posterior cauda that is downturned and deeply excavated, and a twisted, concavo-convex nature of the sagitta (Pl. 1, Fig. 1).

Order ANGUILLIFORMES
Family ANGUILLIDAE
ANGUILLA? sp.

Diagnosis — *Anguilla?* sp. is characterized by a diagonally inclined sulcus that reaches the anterior rim (Pl. 1, Fig. 2).

Family CONGRIDAE
"CONGER" DISSIMILIS Frizzell and Lamber, 1962

Diagnosis — *"C." dissimilis* is characterized by an excavated cauda, thick deposits of colliculum, and a shorter, more narrow sulcus (Pl. 1, Fig. 3).

ARIOSOMA sp.

Diagnosis — *Ariosoma* sp. is characterized by a non-excavated to slightly excavated cauda, small deposits of colliculum, and a longer, wider sulcus (Pl. 1, Fig. 4).

CONGER? VETUSTUS
Frizzell and Lamber, 1962

Diagnosis — *Conger? vetustus* is characterized by its lower height (as compared to other congrids), a deeply impressed area, and a lack of a dorsal dome (Pl. 1, Fig. 5).

Order SILURIFORMES
Family ARIIDAE
ARIUS sp.

Diagnosis — The lapillus of *Arius* sp. is characterized by a sulcus on the outer face and an umbo on the inner face (Pl. 1, Fig. 6).

Order GADIFORMES
Family BREGMACEROTIDAE
BREGMACEROS TROELLI?
Frizzell and Dante, 1965

Diagnosis — *Bregmaceros troelli?* is characterized by its minute size (maximum length—2.0 mm), an inverted scutiform shape, and a widely separately ostium and cauda (Pl. 1, Fig. 7).

Family OPHIDIIDAE
PREOPHIDION STINTONI
Frizzell and Dante, 1965

Diagnosis — *Preophidion stintoni* is characterized by its biconvex, seed-like shape, a completely enclosed sulcus, and a divided sulcus (Pl. 1, Fig. 8).

OPHIDION? sp.

Diagnosis — *Ophidion*? sp. is characterized by its very obvious, almost completely enclosed sulcus and subpyriform shape (Pl. 1, Fig. 9).

Order BERYCIFORMES
Family Unknown
BRAZOSIELLA sp.
Frizzell and Dante, 1965

Diagnosis — *Brazosiella* sp. is characterized by its obvious, slightly recurved sulcus, elongated area, prominent crista superior, and slightly upward directed ostium (Pl. 1, Fig. 10).

Family HOLOCENTRIDAE
MYRIPRISTIS CREOLA
(Frizzell and Lamber, 1961)

Diagnosis — *Myripristis creola* is characterized by its sulcus located on the dorsal margin, scutiform shape, and caudal keel (Pl. 1, Fig. 11).

Order PERCIFORMES
Family SERRANIDAE
ALLOMORONE sp.

Diagnosis — *Allomorone* sp. is characterized by its long, narrow, straight cauda with only the posterior downturned, narrow, elliptical ostium, and subelliptical shape (Pl. 1, Fig. 12).

Family SCIAENIDAE
CORVINA INTERMEDIA (Koken)

Diagnosis — *Corvina intermedia* is characterized by its wide ostium, a sharply downward bent cauda, and a rounded anteroventral margin (Pl. 1, Fig. 13).

EKOKENIA sp.

Diagnosis — *Ekokenia* sp. is characterized by its slightly downward flexed cauda, a rectangular-shaped, very obvious depressed area, and a very prominent crista superior (Pl. 1, Fig. 14).

JEFITCHIA CLAYBORNENSIS (Koken)

Diagnosis — *Jefitchia claybornensis* is characterized by its downturned cauda, narrow ostium, and subquadrate shape (Pl. 1, Fig. 15).

Order PLEURONECTIFORMES
Family SOLEIDAE
ESOLEA TEXANA Frizzell and Dante, 1965

Diagnosis — *Eosolea texana* is characterized by its subcircular shape, small size (maximum length-2.2 mm.), and a sinuous, undivided sulcus (Pl. 1, Fig. 16).

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THE AGE OF THE BAITOA FORMATION, DOMINICAN REPUBLIC, USING MOLLUSCA FOR CORRELATION

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ABSTRACT

In an attempt to prove that mollusks may be used for inter-formational correlation, a study was undertaken to ascertain the age of the shallow-water Baitoa Formation, which has proved barren of micro-guide-fossils (planktic foraminifera or clacareous nannofossils). Only a limited number of gastropod species from the genera *Orthaulax, Murex, Chicoreus, Typhis, Vasum,* and *Fasciolaria* were examined but by utilizing their "concurrent ranges" the age was determined to be late lower Miocene (Burdigalian) just as the formation was originally thought to be by Cooke.

The classic method of studying fossils, both mega- and micro-, has been for a worker to examine a fauna and prepare a monograph on the entire group. In the last century we had a number of these works, often attaining epic proportions, such as Dall's "Tertiary Faunas of Florida" (1890-1903), as well as numerous European efforts of equal magnitude. In more modern times we have seen this trend continue with the primary change being photographs instead of engravings (a change not always for the better) and even the most recent monographs, such as Woodring's impressive study of the Gatun fauna (1957-1973), are basically no different from those of a century ago.

This approach has one serious flaw in that no person can possibly know all about every species from every locality, and so errors in identification are inevitable. When I began to work in the field of Paleontology I decided a different approach might be more useful in the long run — and that was to take a particular genus and look at it through time. Thus subtle changes due to the continuing evolutionary shifts would be more conspicuous. With more precise identifications inter-formational correlation would be refined. And more importantly, incorrect correlations based upon *incorrect* identifications would be eliminated.

For most of the Tertiary formations of the western Atlantic we now have good inter-basinal correlation by means of planktic foraminifera or calcareous nannofossils. But the extremely shallow water Baitoa Formation of the Dominican Republic (text fig. 1) has proved to be barren of such invaluable aids and we must, of necessity, turn to the mollusks, as they are all we have. This paper, in a sense, is a test of my theory that mollusks can be utilized for inter-basinal correlation — if, and only if, the identifications are based upon a detailed knowledge of a particular genus of Mollusca. Being essentially non-pelagic, mollusks tend to develop into highly regional species and in the modern fauna there are more species limited to a narrow geographic (or ecologic) range than otherwise. In the western Atlantic the number of species in common between the Gulf of Mexico, for example, and the Greater Antilles is minimal and we would not expect the ancient faunas to be greatly different. But if we can find a few species in common between two disjunct fossil faunas, particularly species restricted to a short time span (*i.e.*, index fossils) then we should be able to use these *almost* as well as microfossils for geologic correlation.

Because of the problems that could be introduced by my doing the very thing I mentioned above, I shall employ only those genera as I personally, or one of my students, have studied in some depth. Thus, the Typhinae were studied by Richard Gertman (1969), the Fasciolariidae by Amanda Hunt (unpubl. Tulane dissertation, 1975), and the Muricidae and Vasidae by me (Vokes, 1963, 1965, 1966). Of particular concern, the extinct strombid genus *Orthaulax* was treated by Vokes and Vokes (1968). Although far from a representative portion of the fauna I will limit myself to these few groups because I feel confident of my identifications; in other genera I do not.

The geological setting of the Baitoa is of no particular value in establishing its age. It lies unconformably upon the upturned beds of the Tabera Formation (text fig. 2), which has long been considered as Oligo-

cene because of the presence of *Lepidocyclina* (Vaughan *et al.*, 1921, p. 61). This age is confirmed by W. H. Akers (personal communication), who dates the Tabera outcrop at Baitoa as Neogene Zone 3 (late Oligocene). The Baitoa is thought to be overlain conformably, or at least paraconformably, by the Cercado Formation but this contact has not been seen. As the Baitoa is identifiable only in the immediate vicinity of the type locality, the stratigraphic relationship with the overlying beds is totally conjectural. There is no reason, from the physical standpoint, that the Baitoa could not be basal Cercado as originally suggested by Cooke (1920).

Gabb (1873), who made the first detailed study of the geology of the Dominican Republic, considered that there was but a single formation of late Miocene age overlying the Tabera (although he did not use that name). Maury (1917, 1919) separated the Cercado and the Gurabo "formations" on a faunal basis, as the Cercado is shallow and the Gurabo is deep-water, but her party did not get to Baitoa due to political difficulties and she did not treat the Baitoa except to put the "*Orthaulax* beds" below the Cercado. The formation was named by Cooke (1920, p. 220), who did not discuss the stratigraphy but only gave a chart with the Baitoa indicated as the basal member of the Cercado, with a Burdigalian age indicated for the Baitoa, which he correlated with the Chipola Formation of northwest Florida. Although the type localities and lithologies were covered in the subsequent study by Vaughan *et al.* (1921) there still was no basis given for the assignment to a Burdigalian age. Only in a third paper (Cooke, 1921) on the occurrence of *Orthaulax* at Baitoa did Cooke state that the fauna of "corals and mollusks with which the *Orthaulax* is associated have been studied by Vaughan and Woodring, who correlate them with the Burdigalian fauna of Europe and with the fauna of the Chipola marl member of the Alum Bluff formation of Florida" (1921, p. 24). But examination of the faunal lists of the material "studied" (Vaughan *et al.*, 1921, pp. 113, 114) sheds little light on this statement as all of the species listed are either "cf." or "n. sp." or are species described by Gabb or Maury.

Recent work in planktic foraminifera and calcareous nannofossils has caused a revision in the ages of many of our Caribbean formations. Much of this is because the principal work that has been used as a standard of reference is the Bowden, Jamaica, molluscan fauna monographed by Woodring 50 years ago (1925, 1928). At that time he called this formation "middle Miocene" and all subsequent Caribbean correlation has been based upon comparisons with it. But we now know (Lamb and Beard, 1972, p. 32) that the Bowden shell bed is basal Pleistocene and thus almost all of the later Neogene formations are being moved upward — the Gurabo Formation should be dated as uppermost Miocene or early Pliocene — N.17 to 19 (Dr. Akers, pers. comm.) instead of middle Miocene. The shallow-water Cercado Formation is as "undatable" as the Baitoa but on molluscan affinities it seems to be much closer to the age of the Gurabo than to the Baitoa, which it resembles more nearly on an ecologic basis. In spite of the similarity of facies between the Baitoa and the Cercado there are very few species in common between the two; but there are a large number of species in common between the Cercado and the Gurabo, including the so-called "guide fossil" *Aphera islacolonis* (we have rare specimens in the Gurabo Formation from TU 1211 and 1250), in spite of the differences in facies. As a guess, they will work out to be the same age — either late upper Miocene or lowermost Pliocene, instead of early and late middle Miocene. Where does this leave the Baitoa? Is it still Burdigalian or should it be moved into the now vacant middle Miocene slot? Is it the basal conglomerate of the Cercado Formation? This study is an attempt to find out.

Most of the species of mollusks from Santo Domingo were originally described by Gabb (1873), who gave no locality data whatsoever. Since Gabb's time there have been three principal collections made in the beds of the Yaque Group. The first was by the Maury party (1917) but they were prevented from even reaching Baitoa by a revolution. So, although they have good stratigraphic control for the Cercado and Gurabo, they did nothing with the Baitoa. The second party was that of the

Text figure 1. Boulder showing large pebbles and coral fragments, Baitoa Formation at TU 1226, type locality of the formation.

Text figure 2. Baitoa Formation at the type locality, seen resting on the upturned beds of the Oligocene Tabera Formation. (Line indicates the contact.)

U.S. Geological Survey, under the direction of Vaughan (Vaughan *et al.*, 1921), who made extensive collections in all three units. And finally we (my husband and I) collected there in 1976, 1977, and 1978, again in all three units. In spite of these fairly intensive surveys, some of Gabb's species have yet to be rediscovered. With these we must use deductive means for determining the stratigraphic position. But fortunately most of his species have been pinned down and it appears that many are from the Baitoa Formation. From the condition of his material it has been suggested that he had some as-yet undiscovered locality, for at the type Baitoa the preservation is not very good. But this is conjecture and he may have simply spent a lot of time at Baitoa for almost all of his species have been taken there by us or the U.S.G.S. party.

The single most "important" species, that which caused the original correlation of the Baitoa with the Chipola, is *Orthaulax inornatus*. Gabb described this strange strombid from Santo Domingo and in his collection he had several specimens. The matrix of the type lot is typical of Baitoa in that certain of the specimens are filled with a concrete-like siltstone, whereas other examples are completely clean. The U.S. Geological Survey obtained a broken specimen at Baitoa, which prompted Cooke's study of the genus. Ramírez (1956, pl. 1, fig. 7) also reported the species and we have collected three specimens (Plate 1, fig. 1) at Baitoa, none any better than the broken U.S.G.S. specimen figured by Cooke (1921, pl. 2, fig. 6). However, on the road into Baitoa (TU 1253 = USGS 8559) we also collected a somewhat more complete, although poorly preserved, example (Plate 1, fig. 2).

Our studies on the variability of *Orthaulax* (Vokes and Vokes, 1968) cast doubt on the specific distinctness of the Chipola *O. gabbi* Dall *vs.* the Dominican *O. inornatus*. With this additional material now at hand there is even less doubt that the two forms are synonymous. Examination of the five specimens in the type lot of *O. inornatus* shows certain minor differences between these and the Chipola examples of *O. gabbi*. The protoconch is slightly larger in diameter in *O. inornatus* and the spire is not quite as elongated. However, even in these five specimens there is such variability that Pilsbry (1922, p. 369) named three of the lower spired ones as subspecies *altilis*. In our study the opinion was expressed, which is still held today, that the Aquitanian Tampa Limestone *O. pugnax* (Heilprin) is also a synonym of *O. gabbi* and hence *O. inornatus*. Unfortunately, I

PLATE 1

Figures

1, 2. *Orthaulax inornatus* Gabb (× 1)
1. USNM 263951; height (incomplete) 31.0 mm, diameter 29.5 mm.
Locality: TU 1226, Baitoa Formation.
2. USNM 263952; height 64.0 mm, diameter 40.0 mm.
Locality: TU 1253, Baitoa Formation.

3, 4. *Orthaulax gabbi* (Dall (× 1¼)
3. USNM 645902; height 52.0 mm, diameter 23.0 mm.
Locality: TU 457, Chipola Formation.
4. USNM 645901, height 55.0 mm, diameter 30.0 mm.
Locality: TU 458, Chipola Formation.

5, 6. *Fasciolaria kempi* Maury
5. (× 1) USNM 263953; height 106.8 mm, diameter 37.8 mm.
Locality: TU 711, Chipola Formation.
6. (× 1¼) USNM 263954; height (incomplete) 38.7 mm, diameter 23.9 mm.
Locality: TU 1226, Baitoa Formation.

7, 8. *Chicoreus dujardinoides* (Vokes)
7. (× 1½) USNM 263955; height 34.5 mm, diameter 19.0 mm.
Locality: TU 820, Chipola Formation.
8. (× 1¼) ANSP 4003; height 46.5 mm, diameter 30.0 mm.
Locality: "Santo Domingo," ? Baitoa Formation.

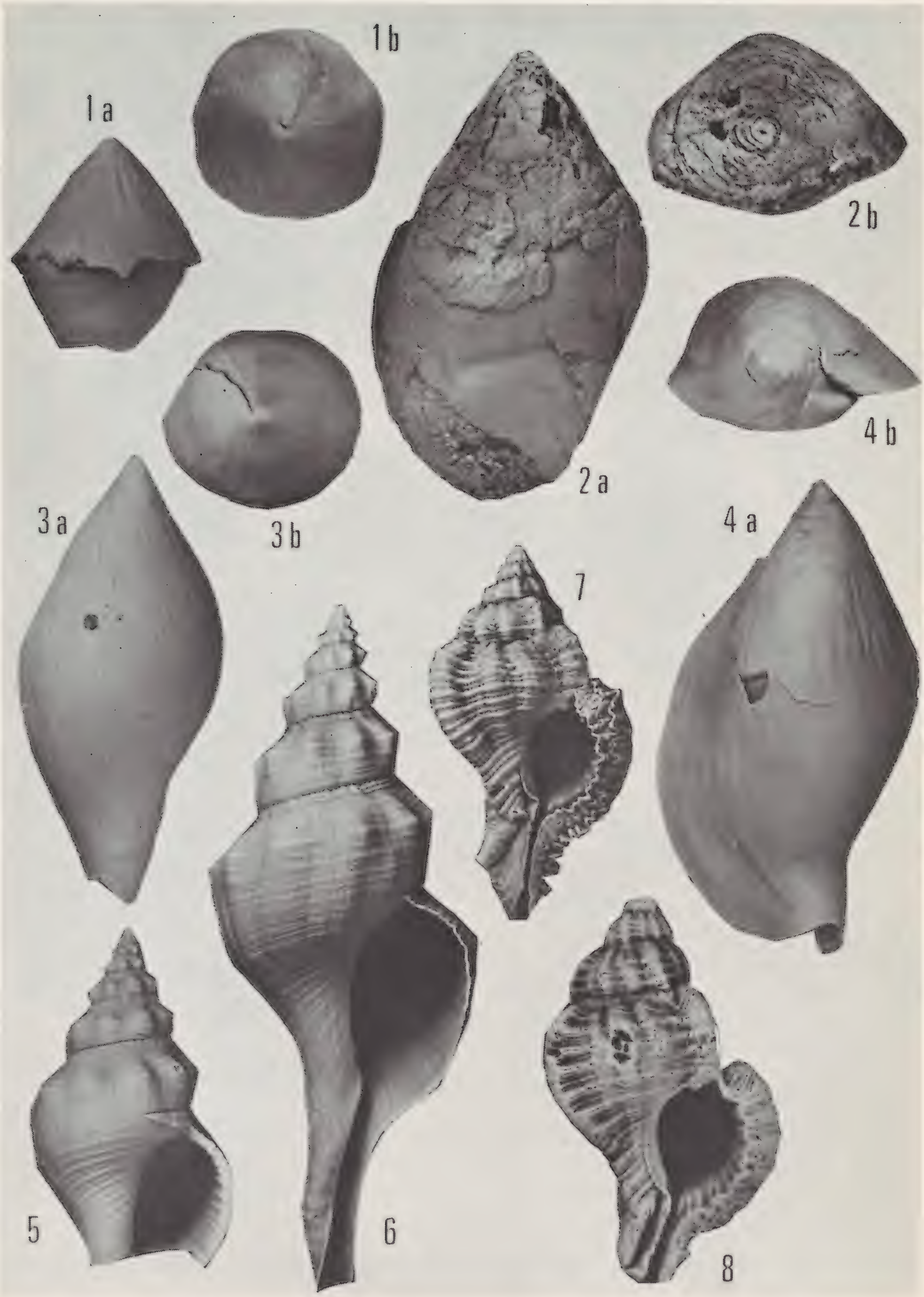


PLATE 1

know of no examples of *O. pugnax* with the protoconchs preserved but the general shape of the specimens extant shows no discernable differences between the Tampa and the Chipola specimens. As noted in the previous *Orthaulax* paper (Vokes and Vokes, 1968, p. 74), there is one specimen from the Tampa that is identical to the type of *O. inornatus*, as it was identified by Dall (1915, p. 86). Likewise, the type of *O. inornatus altilis* (Pilsbry, 1922, pl. 30, fig. 18) shows an outline more like that of *O. pugnax* or *O. gabbi*. From the variability seen in the Chipola specimens of "*O. gabbi*," of which we have hundreds, all of the specimens presently known of both *O. inornatus* and *O. pugnax* may be matched exactly. The cross-sectional outline may be circular (Plate 1, fig. 3) or triangular, (Plate 1, fig. 4) the spire may be high or low. The only conclusion possible is that there is such infraspecific variation in *Orthaulax* spire height and outline are essentially meaningless. The matter of the protoconch to me is more bothersome but at this time I can see no reason not to accept it as a geographical variation within the species. The alternative is to accept them as different species, which really does not change the situation greatly as there is no other formation where this exact variant is known to occur.

The same species also occurs in the Oligocene Browns Town Formation of Jamaica (TU 1015), and in the Pirabas Limestone of Brazil, which is probably equivalent to either the Tampa or Chipola in age. So it seems likely that the various occurrences of *Orthaulax inornatus* are no younger than Burdigalian, but this is by no means certain.* In fact, on the basis of

*In the U.S. National Museum there is a collection made from 3 km northeast of Comendador (now Elias Piña), very near the Haitian border, that contains four examples of unquestionable *O. aguadillensis* and one of unquestionable *O. inornatus*. They are not the same species, small examples of *O. aguadillensis* are readily separable from comparably sized examples of *O. inornatus*. The fossils occur in what has been called the "lower Las Cahobas Formation." At Elias Piña the beds have been dated by Dr. Akers (personal communication) as N. 13, middle Miocene. Perhaps this locality represents the time of transition between *O. inornatus* and *O. aguadillensis*. The rest of the associated fauna fits in with an intermediate position. There is a *Turbinella* like *T. valida* Sowerby but with a less sloping shoulder, a big *Terebra* most like *T. sulcifera* Sowerby but becoming smooth at an earlier stage than the latter species, a totally flat-topped *Conus* that is unlike any species in the area, and *Pachycrommium guppyi* (Gabb), which occurs in the Baitoa, Cercado and Gurabo formations. The only other identifiable species is *Strombus proximus* Sowerby, which occurs in the Cercado and the shallow-water portions of the Gurabo Formation. According to Dr. Akers (personal communication) the foraminifera are all extremely shallow water and give no definate age indications beyond "middle Miocene to Recent."

PLATE 2

Figures

1-3. *Vasum tuberculatum* Gabb
   1. (× ¾) ANSP 2624 (holotype); height 111.0 mm, diameter 86.0 mm.
      Locality: "Santo Domingo," Baitoa Formation.
   2. (× 2) USNM 263956; height 40.7 mm, diameter 29.3 mm.
      Locality: TU 1196, Chipola Formation.
   3. (× 1½) UCMP 14670; height 55.8 mm, diameter 39.0 mm.
      Locality: TU 1269, Cantaure Formation.

4, 5. *Vasum dominicense* Gabb
   4. (× 1) ANSP 2623 (lectotype); height 60.0 mm, diameter 37.0 mm.
      Locality: "Santo Domingo," ? Baitoa Formation.
   5. (× 2) USNM 263957; height 33.5 mm, diameter 17.4 mm.
      Locality: TU 1196, Chipola Formation.

6, 7. *Vasum pugnus* Pilsbry and Johnson (× 1)
   6. ANSP 2626 (holotype); height 80.0 mm, diameter 50.0 mm.
      Locality: "Santo Domingo," ? Baitoa Formation.
   7. USNM 263958; height (incomplete) 71.6 mm, diameter (incomplete) 35.5 mm.
      Locality: TU 547, Chipola Formation.

PLATE 2

the material we have seen, it is probable that there are but two valid species of *Orthaulax* (if one excludes the bizarre ancestral Oligocene *O. hernandoensis* that does not cover the spire). One of these is the smaller, less massive, usually (but not always) high spired *O. inornatus* and the only other is the very massive, much larger (specimens may weigh several pounds), low spired *O. aguadillensis* Maury.

It would appear that *O. inornatus* was replaced by the more massive *O. aguadillensis*, for although originally described as coming from beds of "Oligocene" and "lower Miocene" age in almost every limestone formation of the Caribbean (by one or another name) most of these formations are now known to be younger, usually upper Miocene in age. In the southern Rio Yaque Group, in Santo Domingo, the species is common in beds just below those dated by Dr. Akers (personal communication) as about N.18 or Mio-Pliocene. The Quebradillas Limestone of Puerto Rico is now dated as uppermost Miocene by Seiglie and Moussa (1975, p. 2315) and the "Aguadilla Limestone" (type locality for *O. aguadillensis*), is the same as the Los Puertos Limestone that immediately underlies the Quebradillas (the two have been combined in an Aymamon Limestone but that name has been rejected by recent workers in Puerto Rico).

In the Muricidae, the group where I have concentrated most of my attention, we see very few species from the Baitoa. One we collected there is *Murex messorius* Sowerby, which is a good guide to the Neogene (ranging from the lower Miocene to the Recent), but which does not occur in the Chipola. *Murex messorius* has been reported from the Pirabas Limestone of Brazil (as *Murex sutilis* White), so it is not too surprising that it be found at Baitoa.

The only other muricid we have found at Baitoa is *Typhis obesus* Gabb. This presumably is the type locality as it has not been taken elsewhere in the Dominican beds. The species is common in the Chipola Formation but also is common in the Gatun Formation of Panamá, probably late Miocene in age, so one might consider it as a "false prophet." It is curious that the species has not been taken in either the Cercado or the Gurabo formations, which more nearly match the Gatun in age. One can only assume the Cercado is too shallow water and the Gurabo is too deep. Several other species of *Typhis* are found in these beds but not *T. obesus*.

So far we are not doing too well in our efforts at correlation. But in the Gabb collection at the Academy of Natural Sciences of Philadelphia there is a beach-worn specimen (ANSP 4003) that was not identified by Gabb (Plate 1, fig. 8). Neither, needless to say, was the locality given. But this specimen is almost certainly the same as *Chicoreus dujardinoides* (Vokes) from the Chipola (Plate 1, fig. 7). This species is not uncommon in the shallow water calcarenite beds of Farley Creek and the upper beds along the Chipola River. But so far as is known it occurs nowhere else and so maybe it is *the* unequivocal guide fossil we seek. If we make the assumption (based upon its appearance) that Gabb's specimen did indeed come from Baitoa then here is the first unquestionable species that is correlatable with, and only with, the Chipola Formation.

There are a total of six species of *Vasum* described from the beds of Santo Domingo. Of these we now know *V. aedificatum* (Guppy) is found in the Cercado Formation (TU 1230) and the Gurabo (TU 1225); *V. gurabicum* Maury is found in the Gurabo (TU 1211, 1215-common, 1225, 1246, 1277, 1282) and the Mao Adentro Limestone (TU 1252). The most widespread species is *V. haitense* (Sowerby), which is found in the Baitoa, the Chipola, and the Pirabas, but also in the Gurabo (although not yet in the Cercado) — another of our "false prophets."

This leaves three species, two described by Gabb, and the third described by Pilsbry and Johnson from Gabb's material. Of these, *V. tuberculatum* Gabb (Plate 2, fig. 1) was reported from Baitoa (USGS 8668) by Vaughan *et al.* (1921, p. 113), although we have not collected it there. This species is characterized by bifed shoulder spines and is similar to the Recent *V. rhinoceros* (Gmelin) from the east coast of Africa, although the latter has only three columellar plications in contrast to the four or five (three strong, with one or two weaker between them) of *V. tuberculatum*.

From the Cantaure Formation of Venezuela (TU 1269) we have a single specimen of *V. tuberculatum* (Plate 2, fig. 3, from the collections of the University of California,

Berkeley) and another is in the collection of Mr. John Gibson-Smith, of Caracas, Venezuela. The Cantaure Formation is the same Burdigalian age as the Chipola (see Hunter and Bartok, 1974, p. 147), thus, it was with great pleasure that a specimen, collected in the upper beds of the Chipola (TU 1196) was recognized as *V. tuberculatum* (Plate 2, fig. 2). As the species has been identified from no other western Atlantic formations we seem to be in possession of a second infallible guide fossil. But such is not the case, for in the Aquitanian of France is another species named by Peyrot (1928, p. 29) as *V. aquitanicum* that is indistinguishable from our small Chipola specimen. But it may have taken that length of time to cross the Atlantic.

Vasum dominicense Gabb is still a question mark. Vaughan *et al.* (1921, p. 140) reported that they had a specimen from the Gurabo Formation at Bluff 2 on the Rio Mao (USGS 8528) but this specimen cannot be located in the USNM today. Neither we nor Maury collected any specimens of *V. dominicense* but we do have a large example of *V. gurabicum* from a locality not far from that of the U.S.G.S. (TU 1225) that looks not unlike *V. dominicense* and might be the basis for a mistaken identification. Gabb had two specimens, the larger of which (Plate 2, fig. 4) is worn but looks very much like it might have come from Baitoa and which yielded a friable sand matrix identical to that recovered from one of the well-preserved paratypes of *Orthaulax inornatus*. The smaller (see Pilsbry, 1922, pl. 27, fig. 4) is better preserved but the specimen is now lost (E. Scott, 1978, *in litt.*). From the uppermost beds along Farley Creek (TU 1196) in the Chipola Formation we have two specimens (Plate 2, fig. 5) of an undescribed *Vasum* that are very close to Gabb's species, but which show small spines at the shoulder that Gabb's specimens do not appear to have. It has the appearance of being intermediate between *V. dominicence* and *V. gurabicum*. Or it may be within the range of variability of *V. dominicense*, but we cannot say at this time. Certainly it is the closest form yet found to *V. dominicense*.

The last species of *Vasum* is *V. pugnus**, described by Pilsbry and Johnson (1917, p. 167) from a specimen in Gabb's collection (Plate 2, fig. 6). From the hardened matrix in the specimen it is assumed that the specimen came from Baitoa, but this assumption has not been proved or disproved by additional collecting. The miserable holotype remains unique. I believe the reason Gabb did not name it was because of the poor nature of the specimen. It is impossible to say even how many columellar plications the species has due to the infilling with a matrix akin to concrete (which is typical of Baitoa).

As poor as the specimen of *V. pugnus* is, it is possible to say that it is unlike any other species of *Vasum* described from the New World. There is an Aquitanian species, *V. stephanense* Peyrot, from France, that is the nearest kin but differs in having a higher spire and, consequently, more elongate shell. Interestingly, Peyrot (1928, p. 32) comments that his unique specimen is rolled, the spire is broken and the outer lip is mutilated. Obviously this type of *Vasum* lived in very shallow water, which also suggests Baitoa.

Once again there is a single specimen (Plate 2, fig. 7), even worse than the type of *V. pugnus*, which has been taken from the environs of a coral reef in the Chipola Formation (TU 547). The most conspicuous feature visible on this wretched creature is the subsutural constriction, which is most like that seen in *V. pugnus*. The shoulder nodes are somewhat stronger in the Chipola specimen but this might well be in the range of variability. In any case it is the nearest relative we have found in the New World.

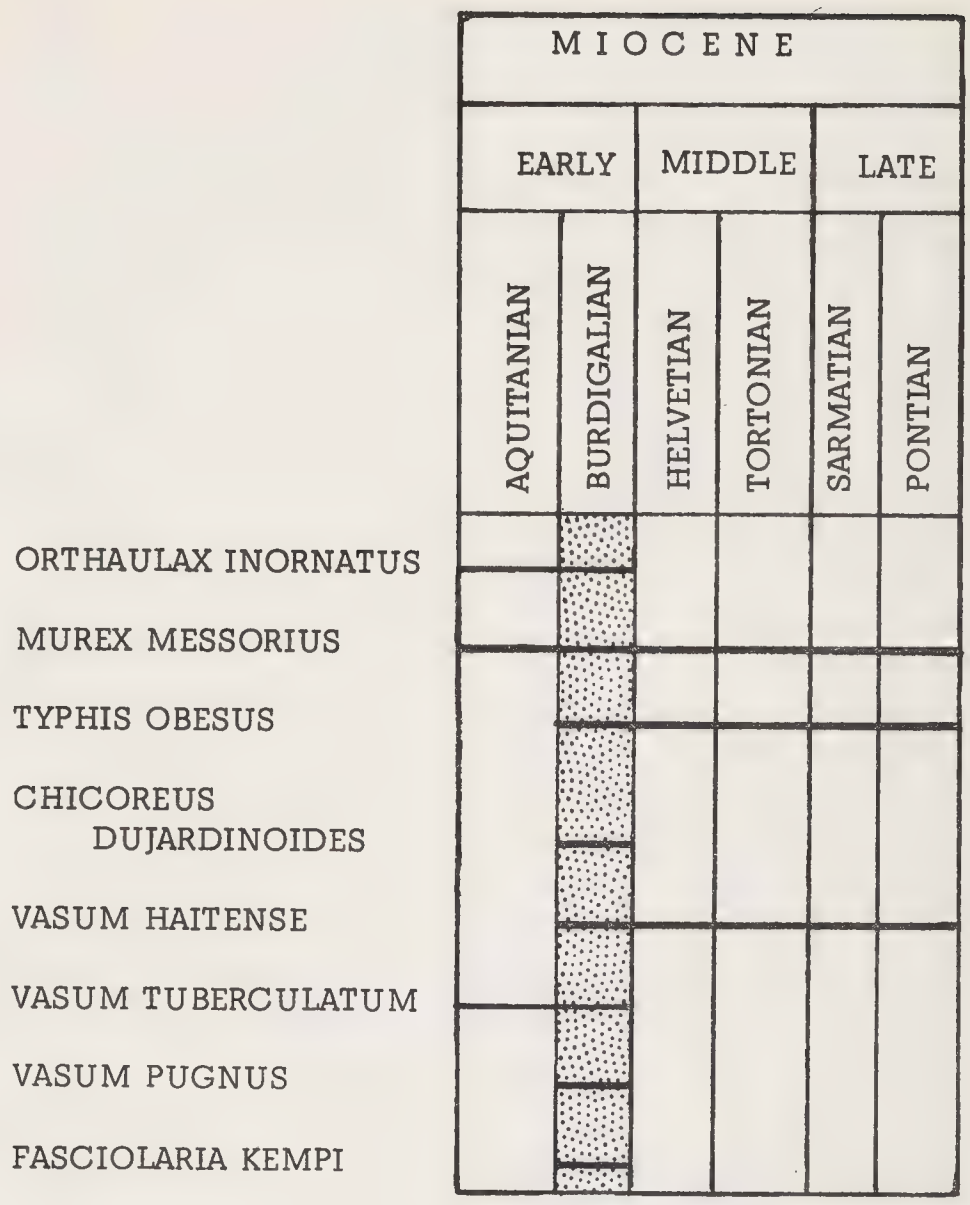
One final family, in which there is a single species of interest to us, is the Fasciolariidae. One species of *Fasciolaria* s.s. (type: *F. tulipa*) unfortunately was described as two species — *semistriata* and *intermedia*, both on the same page by Sowerby (1850, p. 49), with neither figured. Gabb collected two species in Santo Domingo and decided they must be the two species of Sowerby and so assigned one name to each. The true *F. semistriata* occurs in both the Cercado and Gurabo formations and is the more common of the two forms. The second species, *F. kempi*, which is referred to the subgenus *Triplofusus* (type: *F. gigantea*), was named sub-

*Inexplicably spelled *V. pugnans* in Vokes, 1966.

sequently by Maury (1910) from one of Gabb's specimens. There is no doubt that this species comes from the Baitoa Formation. The U.S. Geological Survey collected specimens, as did Ramírez (1956, pl. 1, fig. 2), and we have also collected several examples at Baitoa (Plate 1, fig. 6). Among Baitoa species (excluding those of the genus *Phos*) it would be considered one of the more common. However, all are tailless — our specimen is no better (or worse) than the holotype.

This species has a curious history — it was named by Maury (1910, p. 138) as being from the Chipola Formation. Later (1917, p. 245) she admitted that one of Gabb's specimens had been mixed in with the collections from the Chipola. Undoubtedly someone was comparing it with the Chipola material for, as it develops, the species does occur rarely in the Chipola beds (Plate 1, fig. 5). Thus, in spite of its rather questionable pedigree it becomes our only single species that unequivocally occurs in the Chipola and the Baitoa formations alone. The only other related species is *F. gorgasiana* Brown and Pilsbry, which is found in the Gatun Formation, but which may readily be distinguished by its bigger protoconch and smoother shell.

In summary we can see that with *Fasciolaria kempi* we have the only absolutely unquestionable correlation in the small group we have examined, plus the slightly questionable *Chicoreus dujardinoides*. But if we look at the ranges (text fig. 3) of all the species so far discussed, and consider them from the point of "concurrent ranges" as is done for foraminifera or nannofossils, then we note that the *only* possible age for the Baitoa Formation is late lower Miocene, the same as the Chipola, with which it was originally correlated nearly 70 years ago. Furthermore, in my opinion, we have proved that molluscan species may be utilized for correlation just as micro-fossils are, providing the specific determinations are sufficiently precise.



Text figure 3. Geologic ranges of certain molluscan species found in the Chipola and Baitoa formations.

ACKNOWLEDGMENTS

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LOCALITY DATA

457. Chipola Fm., west bank of Chipola River, about ½ mile below Tenmile Creek (SW ¼ Sec. 17, T1N, R9W), Calhoun Co., Florida.

458. Chipola Fm., east bank of Chipola River, above Farley Creek (SW ¼ Sec. 20, T1N, R9W), Calhoun Co., Florida.
547. Chipola Fm., west bank of Chipola River, about 2000 feet above Fourmile Creek (SW ¼ Sec. 29, T1N, R9W), Calhoun Co., Florida.
711. Chipola Fm., west bank of Chipola River, about ¼ mile up from Farley Creek (SW ¼ Sec. 20, T1N, R9W), Calhoun Co., Florida.
820. Chipola Fm., Farley Creek, at bridge of Florida Highway 275 (SW ¼ Sec. 21, T1N, R9W), Calhoun Co., Florida.
1015. Browns Town Fm., Orange Park, east of Claremont, Parish of St. Ann, Jamaica.
1196. Chipola Fm., Farley Creek, north bank about 0.8 mile east of bridge on Florida Highway 275 (NE ¼ Sec. 21, T1N, R9W), Calhoun Co., Florida.
1211. Gurabo Fm., Rio Gurabo, west bank, second bluff below the bridge on Los Quemados-Sabaneta road, Dominican Republic (= USGS 8546).
1215. Gurabo Fm., Rio Gurabo, bluffs on both sides, from the bridge on Los Quemados-Sabaneta road, upstream to approximately 1 km above the bridge, Dominican Republic (= USGS 8539-8543; Maury's Zone D).
1225. Gurabo Fm., banks of large arroyo on west side of the Rio Mao, upstream from Mao Adentro and downstream from Cercado de Mao, about 11 kms (by winding road) south of Mao, Dominican Republic.
1226. Baitoa Fm., type locality, east bank of the Rio Yaque del Norte, below the village of Baitoa, and above the confluence of the Rio Yaque and the Rio Bao, Dominican Republic (= USGS 8558).
1230. Cercado Fm., Rio Caña, east bank, just above the bridge at Caimeto on Los Quemados-Sabaneta road, Dominican Republic (= USGS 8534; Maury's Zone H).
1246. Gurabo Fm., Rio Gurabo, from 1 km to 2 km (airline) upstream from bridge on Los Quemados-Sabaneta road, Dominican Republic (= USGS 8538; Maury's Zone E).
1250. Gurabo Fm., Rio Verde, south bank, just above the ford at the crossing of a side road that connects the Duarte Highway and the La Vega-Moca Highway, about 10 km north of La Vega, Dominican Republic. (One of the few localities mentioned specifically by Gabb, 1873.)
1252. Mao Adentro Limestone, Arroyo Las Lavas, at crossing of Duarte Highway K 18.5 west of Santiago de los Caballeros on road to Navarette, Dominican Republic (= USGS 8663).
1253. Baitoa Fm., road cut on west side of road from Santiago de los Caballeros to Baitoa, 2 km north of the village of Baitoa, Dominican Republic (= USGS 8559).
1269. Cantaure Fm., series of arroyos about 500 yds. south of "Casa Cantaure" [which is literally one house and which is about 400 yds. south of older, now abandoned, house that was the "Casa Cantaure" of Jung, 1965, and others], 14 km (by road) west of Pueblo Nuevo, Paraguaná Peninsula, Venezuela.
1277. Gurabo Fm., Rio Gurabo, both sides, upstream from the horsetrail to 0.5 km above the trail, or approximately 2 km (airline) to 2.5 km above the bridge on Los Quemados-Sabaneta road, Dominican Republic (see Vaughan *et al.*, 1921, pl. 11; = Maury's Zone F).
1282. Cercado Fm., tributary of the Rio Caña to the east, about 1 km above the bridge at Caimeto on Los Quemados-Sabaneta road, Dominican Republic (Maury's Zone I).

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November 9, 1979

REVIEW

A STRUCTURAL, STRATIGRAPHIC AND PETROLOGIC STUDY OF ANORTHOSITES, ECLOGITES, AND ULTRAMAFIC ROCKS AND THEIR COUNTRY ROCKS, TAFJORD AREA, WESTERN SOUTH NORWAY, by H. K. Brueckner. Published by the Geological Survey of Norway, 1977, Bulletin 41, 53 pp., 21 figs., 2 tbls., folding map, $10.00 (distributed in the United States by the Columbia University Press, New York).

The Tafjord area contains Caledonized metamorphic rocks divided into two groups, the 1000 m.y. old Fetvatn Gneiss, a granodioritic gneiss intruded as part of a large plutonic complex during the Sveconorwegian Cycle; and, the Vikvatn Sequence of metasedimentary and metavolcanic rocks of later Pre-Cambrian age, containing anorthosite, eclogite, and anhydrous peridotite. The structure, petrology, and facies metamorphism of the sequences are described and illustrated. A folding map of the area is included.

—H.C.S.

THE GASTROPOD GENUS *VOLUTOCRISTATA* GARDNER AND BOWLES (EOCENE; CALIFORNIA, MEXICO): A SYNONYM OF *LYRISCHAPA* ALDRICH (EOCENE; GULF COAST)

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ABSTRACT

The volutid gastropod genus *Volutocristata* Gardner and Bowles, described from the Eocene of Mexico and California, is shown to be a synonym of the monotypic Gulf Coast Eocene genus *Lyrischapa* Aldrich. As here expanded, the genus *Lyrischapa* includes at least three species, each of which characterizes middle Eocene strata within a different region of North America: *L. harrisi* Aldrich, the type species, in the Gulf Coast region of the southeastern United States; *L. chiapasensis* (Gardner and Bowles), in southern Mexico on the Gulf of Mexico side of the continental divide; and *L. lajollaensis* (Hanna), on the Pacific Coast.

The ancestry and place of origin of *Lyrischapa* are unknown. The geographic distribution of the genus suggests an immediate center of dispersal in the Caribbean region. It may have evolved in that region or it may be an immigrant from the Tethyan paleobiogeographic province. Dispersal of *Lyrischapa* to the Pacific Coast was probably by way of a narrow seaway connection across southern Central America or northwestern South America.

INTRODUCTION

Lyrischapa and *Volutocristata* are similar but poorly known volutid taxa that have been described from Eocene strata in widely separated regions of North America. *Lyrischapa* was erected by Aldrich (1911) as a monotypic genus from middle Eocene deposits (Cook Mountain Formation) in eastern Mississippi. Until recently, this genus has been known from only two small specimens (Palmer, 1937, p. 399). *Volutocristata* was proposed by Gardner and Bowles (1934) to include two similar volutid species: *Plejona lajollaensis* Hanna, from the middle Eocene ("Domengine Stage") of southern California; and *Volutocristata chiapasensis* Gardner and Bowles, the type species, from the middle Eocene of southern Mexico (Chiapas province). Examination of published illustrations of *Lyrischapa* and *Volutocristata* reveals that both taxa possess a distinctive *Conus*-like shape, with prominent peripheral spines. Their most apparent difference is size; figured specimens of *Volutocristata* are more than twice as large as those of *Lyrischapa*.

Recent collecting in the Cook Mountain Formation of eastern Mississippi has resulted in the discovery of several additional specimens of the monotype species *Lyrischapa harrisi* Aldrich, including specimens much larger than the holotype and comparable in size to those of *Volutocristata*. Comparison of these new specimens of *Lyrischapa* with those of *Volutocristata* (including types) reveals that, in addition to similar shape, these taxa also share other morphological attributes including: a bulbous, paucispiral, deviated protoconch; a high, narrow aperture with subparallel margins and a posterior exhalent sinus above the shoulder; an externally varicose and slightly everted outer lip; numerous deep-seated columellar folds, strongest anteriorly; and a shallow siphonal notch, with a correspondingly weak fasciole. Differences between these taxa are largely in the degree of development of these attributes. The close morphological similarity between *Lyrischapa* and *Volutocristata* leads me to conclude that they are congeneric. On the basis of priority, *Lyrischapa* is retained as the proper generic name for this distinctive group of volutid gastropods.

Although *Lyrischapa* and *Volutocristata* are considered congeneric, the species that have been assigned to these taxa appear to be distinct from one another. Accordingly, the genus *Lyrischapa,* as here constituted, includes three known species, each of which characterizes middle Eocene strata within a different region of North America (text figure 1): *L. harrisi* Aldrich, in the Gulf coastal plain of the

Text figure 1. Geographic distribution of *Lyrischapa*.

southeastern United States; *L. chiapasensis* (Gardner and Bowles), in southern Mexico on the Gulf of Mexico side of the continental divide; and *L. lajollaensis* (Hanna), on the Pacific Coast.

The ancestry and place of origin of *Lyrischapa* are unknown. The geographic distribution of the genus suggests an immediate center of dispersal within the Caribbean region. Perhaps *Lyrischapa* evolved from an unknown ancestor in the Caribbean region during Paleocene or early Eocene time and subsequently spread northward during the middle Eocene. Alternatively, the genus may be an immigrant from the Old World Tethyan paleobiogeographic province. Other mollusks with Tethyan affinities have been recognized in the Eocene faunas of the Caribbean region (Palmer, 1967). Entrance of *Lyrischapa* into the Pacific Coast region of North America was probably by way of a narrow seaway connection across southern Central America (Costa Rica, Panama) or northwestern South America (the Atrato trough of western Columbia). Narrow seaways apparently existed across this region during much of the Tertiary period (Olsson, 1932, p. 51-58; Nygren, 1950; Woodring, 1966).

SYSTEMATIC DESCRIPTIONS

Phylum MOLLUSCA
Class GASTROPODA
Subclass PROSOBRANCHIA
Order NEOGASTROPODA
Family VOLUTIDAE
Subfamily FULGORARIINAE Pilsbry and Olsson, 1954
Genus LYRISCHAPA Aldrich, 1911

Lyrischapa ALDRICH, 1911, Bulls. Amer. Paleontology, v. 5, no. 22, p. 11. Type species (by monotypy): *Lyrischapa harrisi* Aldrich.

Volutocristata GARDNER and BOWLES, 1934, Wash. Acad. Sci., Jour., v. 24, no. 6, p. 245. Type species (by original designation): *Volutocristata chiapasensis* Gardner and Bowles.

Diagnosis: Large, obconical volutid shells with a low, coeloconoid spire; prominent peripheral spines; a bulbous, paucispiral, deviated protoconch; a high, narrow aperture with subparallel margins and a posterior exhalent sinus above the shoulder; an externally varicose and slightly everted outer lip; numerous deep-seated columellar folds, strongest anteriorly; and a shallow siphonal notch, which forms a weak fasciole.

PLATE 1
(all figures × 2)

Figures 1-3. *Lyrischapa harrisi* Aldrich 120

1. PRI 2355 (holotype); height 18 mm, diameter 10 mm (copied from Palmer, 1937, pl. 57, figs. 1, 2).
   Locality: Three and a half miles south of Quitman, Mississippi. Cook Mountain Formation, upper middle Eocene.
2. MSGS-02; height (almost complete) 20.5 mm, diameter 11.2 mm.
   Locality: TU 907. Cook Mountain Formation, upper middle Eocene.
3. MSGS-01; height (incomplete) 40.3 mm, diameter (slightly compressed) 24.7 mm.
   Locality: TU 907. Cook Mountain Formation, upper middle Eocene.

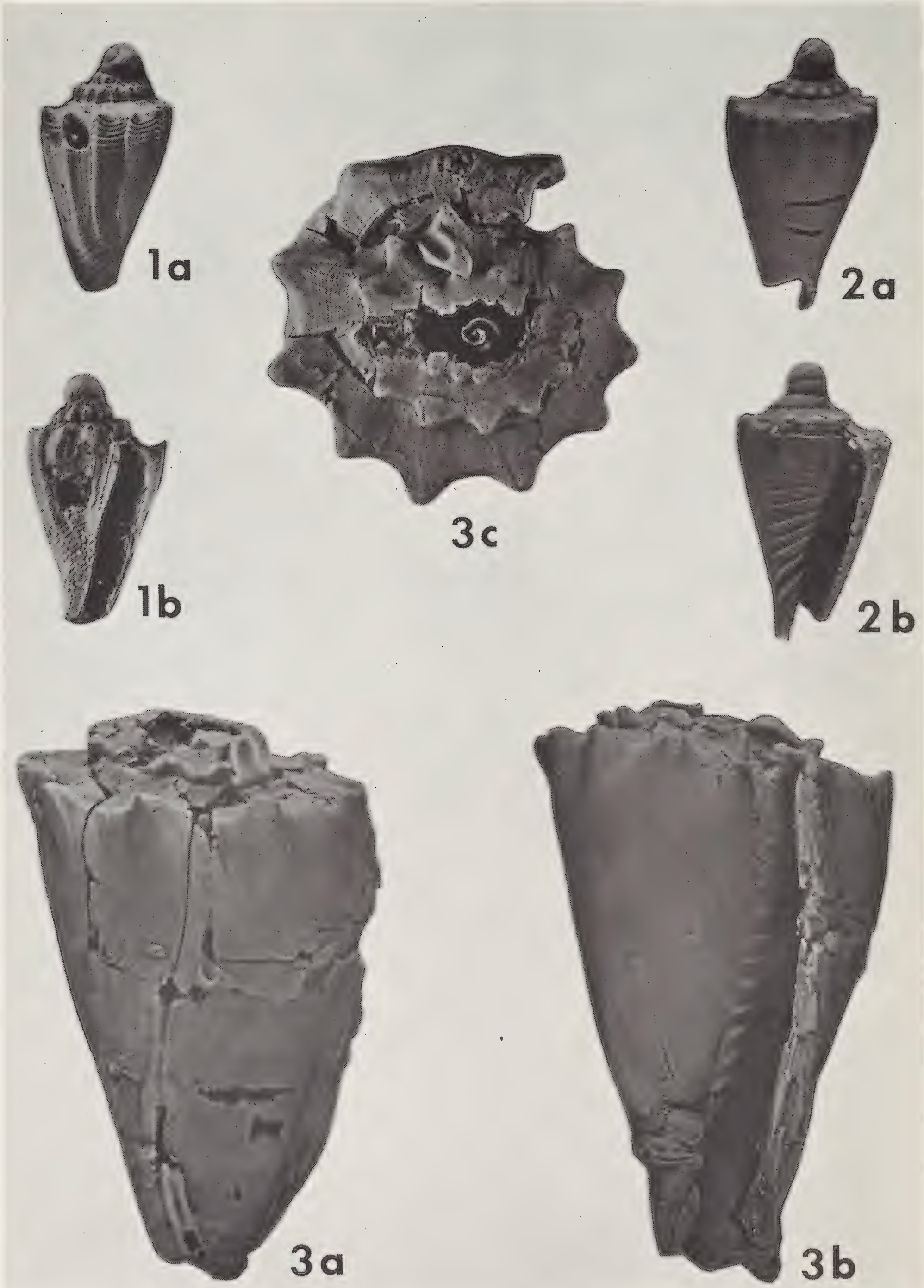

PLATE 1

Discussion: Reference of *Lyrischapa* to the subfamily Fulgorariinae is based upon its bulbous, paucispiral, deviated protoconch; numerous columellar folds; and shallow siphonal notch, with a correspondingly weak fasciole.

LYRISCHAPA HARRISI Aldrich
Plate 1, figs. 1-3; Plate 2, figs. 1a, 1b

Lyria ? sp. DALL, 1890, p. 69, pl. 6, fig. 5a.
Voluta ? sp. ind. DALL, 1890, p. 77, 90, pl. 6, fig. 5a.
Lyrischapa harrisi ALDRICH, 1911, p. 11, pl. 4, fig. 8. PALMER, 1937, p. 399, pl. 57, figs. 1, 2. PALMER and BRANN, 1966, p. 744.

Diagnosis: A *Lyrischapa* with a large, strongly deviated protoconch; acute peripheral spines; a wide concave ramp above the shoulder; widely and almost equally spaced columellar folds, which diminish regularly in size posteriorly; and a thin parietal callus, which does not extend above the suture with the preceding whorl.

Description: Large, obconical, strongly shouldered, with acute peripheral spines and a wide gently concave ramp. Spire low, coeloconoid. Protoconch large, bulbous, smooth, strongly deviated, of two or two and one-half whorls, tip slightly immersed. Post-nuclear whorls four, rapidly expanding, each succeeding whorl enveloping the preceding almost to the shoulder. Early post-nuclear whorls ornamented with 11 to 15 strong costae, which gradually develop into erect, open peripheral spines on the later whorls. Spiral ornamentation of numerous fine lirae, strongest on the early whorls, evanescing on the later whorls. Anterior half of adult body whorl incised with a series of widely spaced oblique spiral grooves, strongest anteriorly. Suture distinct, adpressed to slightly impressed, almost flush with the shoulder on the later whorls. Aperture high, narrow, with subparallel margins and a shallow exhalent sinus above the shoulder. Outer lip smooth, varicose and slightly everted in the adult. Inner lip with 11 or 12 widely and almost equally spaced columellar folds, strongest anteriorly, diminishing regularly in size posteriorly, those on the parietal region reduced to fine lirae. Parietal callus thin, not extending above the suture with the preceding whorl. Siphonal notch shallow, forming a weak fasciole.

Dimensions of holotype: height 18 mm, diameter 10 mm.

Holotype: Paleontological Research Institution (PRI) no. 2355.

Type locality: "Three and a half miles south of Quitman, Mississippi" (Aldrich, 1911, p. 11).

Other localities: Four and a half miles southwest from Enterprise, Clarke County, Mississippi (Palmer and Brann, 1966, p. 744); TU 907; TU 924.

Occurrence: Cook Mountain Formation, eastern Mississippi; late middle Eocene.

Figured specimens: PRI 2355 (holotype); MSGS-01, MSGS-02, locality TU 907; PRI 30014, locality TU 924. Unfigured specimen: PRI 30015, locality TU 924. Material examined: Six specimens, including two apical fragments.

Discussion: Lyrischapa harrisi is distinguished from the other two known species of the genus by a larger protoconch, more rapidly expanding whorls, a broader subsutural area above the shoulder, evenly spaced columellar folds, and a thinner parietal callus that does not extend above the suture with the preceding whorl. The peripheral spines are shorter than those of *L. lajollaensis* and the ramp is wider and more gently sloping. *L. chiapasensis* has a narrow shelf rather than a ramp above the shoulder, blunt rather than acute peripheral spines, and a more depressed spire. The columellar folds of *L. chiapasensis* are more closely spaced and more variable in strength than those of *L. harrisi*.

Lyrischapa harrisi is not a common species in the Cook Mountain Formation of eastern Mississippi. Although it has been recorded from four localities, only eight specimens (including apical fragments) have been found. The species occurs in fine-grained glauconitic sandstone in association with a diverse molluscan fauna, including the stratigraphically restricted species *Cubitostrea sellaeformis* (Conrad).

The late middle Eocene age assigned to the Cook Mountain Formation in eastern

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PLATE 2
(all figures × 2)

Figure 1. *Lyrischapa harrisi* Aldrich 120
PRI 30014; height (incomplete) 38.5 mm, diameter 34.2 mm.
Locality: TU 924. Cook Mountain Formation, upper middle Eocene.

Figure 2. *Lyrischapa chiapasensis* (Gardner and Bowles) 122
USNM 373044; height (almost complete) 39.5 mm, diameter 23.5 mm.
Locality: USGS 13230. San Juan Formation (?), middle Eocene.

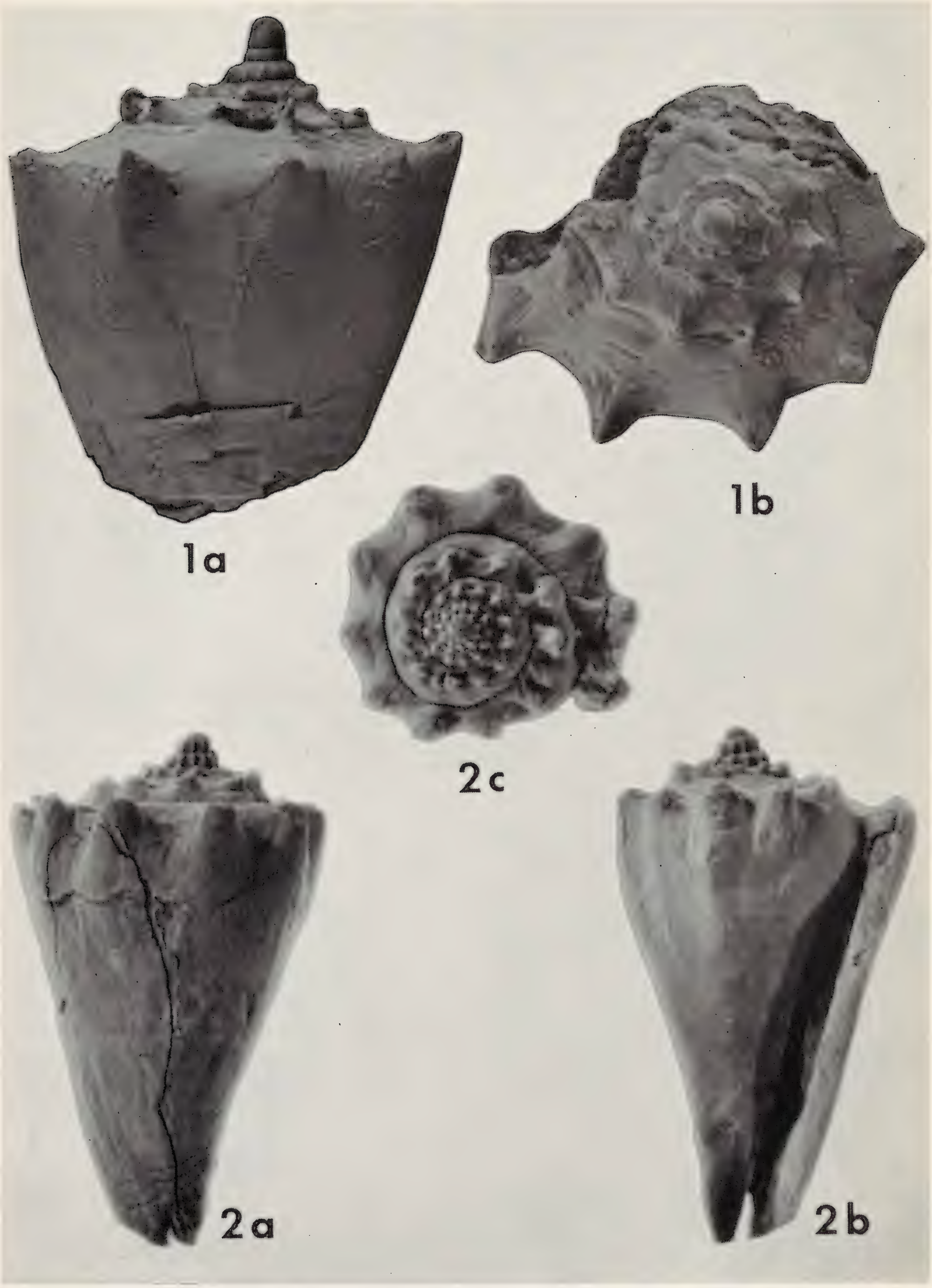

PLATE 2

Mississippi is based upon correlation with the upper part of the Lisbon Formation at Little Stave Creek, Clarke County, Alabama (Stenzel, 1949). The upper Lisbon Formation at Little Stave Creek contains *Cubitostrea sellaeformis* as well as planktonic foraminifers and calcareous nannofossils indicative of a late middle Eocene age (Bandy, 1949; Bybell, 1975).

LYRISCHAPA CHIAPASENSIS (Gardner and Bowles)
Plate 2, figs. 2a-2c

Volutocristata chiapasensis GARDNER and BOWLES, 1934, p. 248, figs. 10-12. MALDONADO-KOERDELL, 1950, p. 213, 214, figs. 42, 43.

Diagnosis: A *Lyrischapa* with a small protoconch; blunt peripheral spines; a narrow shelf above the shoulder; columellar folds of variable strength and spacing, strongest anteriorly; and a thick parietal callus that extends above the suture with the preceding whorl and partly envelops the peripheral spines.

Description: Large, obconical, strongly shouldered, with short blunt peripheral spines and a narrow concave shelf above the shoulder. Spire low, coeloconoid. Protoconch badly worn on the specimens available, small, of approximately two whorls, apparently not strongly deviated. Post-nuclear whorls five, rapidly expanding, each succeeding whorl enveloping the preceding almost to the shoulder. Early post-nuclear whorls ornamented with 11 to 13 prominent axial costae, which gradually develop into erect blunt peripheral spines on the later whorls. Spiral ornamentation of numerous fine lirae, strongest on the early whorls, evanescing on the later whorls. Anterior half of body whorl incised with widely spaced oblique spiral grooves, strongest anteriorly. Suture distinct, impressed, undulating around the axial costae on the early whorls, linear and slightly channeled along the parietal callus band on the later whorls. Aperture high, narrow, with subparallel margins and a shallow exhalent sinus above the shoulder. Outer lip smooth, varicose and slightly everted in the adult. Inner lip with 10 or 11 columellar folds, deep-seated and barely emergent at the aperture, the anterior fold most prominent, the others of variable strength and spacing but gradually diminishing in size posteriorly, those on the parietal wall reduced to faint lirae. Parietal callus thick, extending posteriorly above the suture and partly enveloping the peripheral spines on the preceding whorl. Siphonal notch shallow, forming a weak fasciole.

Dimensions of holotype: height (almost complete) 39.5 mm, diameter 23.5 mm.

Holotype: U. S. National Museum (USNM) no. 373044.

Type locality: USGS loc. 13230, about 12 miles east-northeast of Sayula, province of Chiapas, Mexico.

Other localities: "Caimba, Pichucalco Region (Municipio de Ixtacomitan)," province of Chiapas, Mexico (Maldonado-Koerdell, 1950, p. 213).

Occurrence: Stratigraphic position uncertain, probably San Juan Formation of Frost and Langenheim (1974); middle Eocene.

Figured specimen: USNM 373044 (holotype). Material examined: holotype and paratype (USNM 373045).

Discussion: In addition to the types, eight other specimens (four apparent juveniles and four apical fragments) of *L. chiapasensis* have been reported by Maldonado-Koerdell (1950, p. 213) from a second locality in northwestern Chiapas, Mexico.

The exact stratigraphic position of this species is uncertain. The published locality descriptions include only geographic data. The species probably occurs in strata equivalent or referable to the San Juan Formation of Frost and Langenheim (1974), a nearshore marine and continental clastic unit widely distributed in central Chiapas province. Frost and Langenheim (1974, p. 21-23) have assigned the San Juan Formation to the middle Eocene based upon species of larger foraminifera and corals.

Lyrischapa chiapasensis appears to be more closely related to *L. lajollaensis* than to the type species. Resemblances to *L. lajollaensis* include the small protoconch, the thick parietal callus that partly envelops the peripheral spines on the preceding

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PLATE 3
(all figures × 2)

Figures 1, 2. *Lyrischapa lajollaensis* (Hanna) 124

1. UCMP 30911 (holotype); height 40 mm, diameter 23.8 mm (copy of photograph in the files of the University of California Museum of Paleontology). Locality: UCMP 5062. Ardath Shale, lower middle Eocene.
2. UCMP 14634 (neotype); height (incomplete) 34.8 mm, diameter 25.1 mm. Locality: UCR 4922 (= UCMP 5062). Ardath Shale, lower middle Eocene.

PLATE 3

whorl, and the variable strength and spac ing of the columellar folds. *Lyrischapa chiapasensis* is distinguished from *L. lajollaensis* by a more depressed spire, a shelf rather than a ramp above the shoulder, shorter and less pointed but more erect peripheral spines, a more anteriorly situated suture, and more closely spaced columellar folds. Differences between *L. chiapasensis* and *L. harrisi* have already been noted under the discussion of the latter species.

LYRISCHAPA LAJOLLAENSIS (Hanna)
Plate 3, figs. 1, 2; Plate 4, figs. 1-3

Pejona lajollaensis HANNA, 1927, p. 320, pl. 52, figs. 1, 2. KEEN and BENTSON, 1944, p. 183.
Volutospira (Pejona) lajollaensis (Hanna). CLARK, 1929, pl. 9, figs. 11, 12.
Plejona lajollaensis Hanna. KEEN and BENTSON, 1944, p. 184.
Volutocristata lajollaensis (Hanna). GARDNER and BOWLES, 1934, p. 246, fig. 13. KEEN and BENTSON, 1944, p. 229. GIVENS, 1974, p. 88.

Diagnosis: A *Lyrischapa* with a small, slightly deviated protoconch; acute peripheral spines; a narrow concave ramp above the shoulder; columellar folds of variable strength and spacing; and a thick parietal callus, which extends above the suture with the preceding whorl and partly envelops the peripheral spines.

Description: Large, obconical, strongly shouldered, with acute peripheral spines and a narrow gently to steeply inclined concave ramp. Spire low, coeloconoid. Protoconch small, bulbous, smooth, slightly deviated, of two and one-half whorls, tip slightly immersed. Post-nuclear whorls five or six in the adult, rapidly expanding in size, each whorl of the adult part of the shell enveloping the preceding whorl up to the shoulder so that only the tips of the peripheral spines are exposed. Early post-nuclear whorls ornamented with 9 to 12 strong axial costae, which gradually develop into acute peripheral spines on the later whorls. Spiral sculpture of numerous fine lirae, strongest on the early whorls, evanescing on the later whorls. Anterior half of adult body whorl incised with a series of oblique spiral grooves, strongest and most closely spaced anteriorly. Suture distinct, adpressed to slightly impressed, undulatory around the peripheral spines, almost flush with the shoulder on the later whorls. Aperture high, narrow, with subparallel margins and a moderately deep posterior exhalent sinus above the shoulder. Outer lip smooth, varicose and slightly everted in the adult. Inner lip with 9 to 14 columellar folds, the first or second fold from the anterior end the strongest, the others variable in strength and spacing but gradually diminishing in size posteriorly, those on the parietal wall reduced to fine lirae. Parietal callus thick, extending slightly above the suture with the preceding whorl and partly enveloping the peripheral spines. Siphonal notch shallow, forming a weak fasciole.

Dimensions of holotype: height 40 mm, diameter 23.8 mm.

Holotype: University of California Museum of Paleontology (UCMP) no. 30911. According to written communication from Joseph Peck, Principal Museum Scientist of the University of California Museum of Paleontology, the holotype of *Pejona lajollaensis* Hanna was lost about 10 years ago while out on loan to another institution. Mr. Peck reports that the circumstances surrounding the loss are such that it is very unlikely that the holotype will ever be found. Therefore, another specimen from the type locality is designated below as neotype of this species.

Type locality: UCMP 5062 (= neotype locality UCR 4922, described below).

Neotype: UCMP 14634 (here designated).

Dimensions of neotype: height (incomplete) 34.8 mm, diameter 25.1 mm.

Neotype locality: UCR 4922, at lat. 32° 53′ 43″ N., long. 117° 15′ 6″ W., about 12 feet below top of sea cliff at south end of Torrey Pines State Park, 340 feet south of north end of Torrey Pines Scenic Drive, Del Mar 7.5 minute quadrangle (1967 ed.). Ardath Shale, near top; early middle Eocene, *Rhabdosphaera inflata* Subzone of Bukry (1973), "Domengine Stage" in the provincial Pacific Coast mega-invertebrate chronology (Bukry and Kennedy, 1969; Kennedy and Moore, 1971; Givens, 1974, p. 27-28; Berggren *et al.*, 1978, p. 72).

Other localities: UCR 4923, UCR 4699, UCR 1, UCR 7719, UCR 1838, USGS 12632.

Occurrence: Upper Ardath Shale, San Diego County; upper Llajas Formation, Ventura County; Juncal Formation, beds containing the *Turritella uvasana applinae* fauna of Givens (1974), northern Ventura County. Middle Eocene ("Domengine Stage") of southern California.

Figured specimens: UCMP 30911 (holotype); UCMP 14634 (neotype); UCR 7719/4, locality UCR 7719; UCR 1838/1, locality UCR 1838; UCR 1/601, locality UCR 1. Unfigured specimen: UCR 1/602, locality UCR 1. Material examined: ten specimens.

Discussion: On the basis of numbers of specimens, this is the best known of the three species of *Lyrischapa*. It is widely distributed in strata of middle Eocene ("Domengine") age in southern California and is particularly common in the Llajas Formation in Ventura County.

Lyrischapa lajollaensis shows some variation in height of spire; steepness of the subsutural ramp; and number, strength, and spacing of columellar folds. One young specimen (UCR 1838/1) from the Llajas Formation has evenly spaced columellar folds that diminish regularly in strength posteriorly, similar to those of *L. harrisi*. The other specimens examined, however, have folds of variable strength and spacing. The neotype (UCMP 14634) shows remnants of a checkerboard color pattern on the body whorl. *L. lajollaensis* attains a maximum size considerably larger

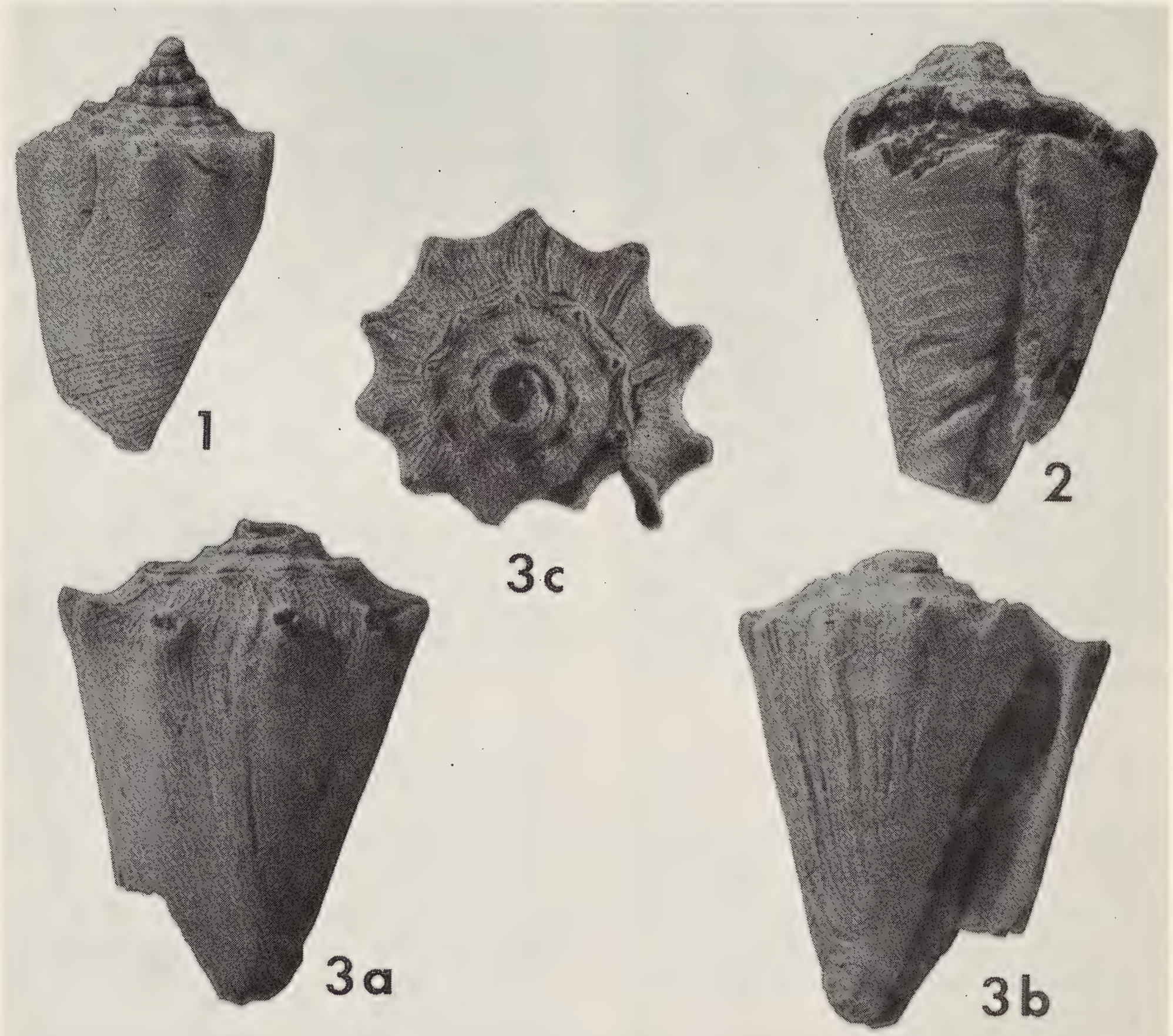

PLATE 4
(all figures × 2)

Figures 1-3. *Lyrischapa lajollaensis* (Hanna) 124

1. UCR 7719/4; height 24.1 mm, diameter (slightly increased by distortion) 13.5 mm.
   Locality: UCR 7719. Llajas Formation, middle Eocene.
2. UCR 1838/1; height (incomplete) 26.4 mm, diameter 18.3 mm.
   Locality: UCR 1838. Llajas Formation, middle Eocene.
3. UCR 1/601; height (incomplete) 28.0 mm, diameter 21.5 mm.
   Locality: UCR 1. Llajas Formation, middle Eocene.

than is indicated by the figured specimens. An unfigured internal mold (UCR 1/602) from the Llajas Formation, lacking the tip of the spire and the anterior third of the body whorl, has a height of 52 mm and a diameter of 47 mm. The complete shell probably exceeded 70 mm in height.

Comparison of *L. lajollaensis* with *L. harrisi* and *L. chiapasensis* has been made under the discussions of those species.

ACKNOWLEDGMENTS

I am grateful to David T. Dockery of the Mississippi State Geological Survey for allowing me to examine specimens of *Lyrischapa harrisi* in his collections and for photographing these specimens. Appreciation is also expressed to the following individuals and institutions for the loan of specimens utilized in this study: Jack D. Mount, Director of Museum, Department of Earth Sciences, University of California, Riverside; Joseph H. Peck, Principal Museum Scientist, Museum of Paleontology, University of California, Berkeley; and Frederick J. Collier, Collections Manager, Department of Paleobiology, U. S. National Museum of Natural History. Finally, special thanks are due my wife Florence for her assistance in the collection and preparation of specimens for this study.

LOCALITY DATA

Tulane University Locality Numbers

TU 907. Cook Mountain Formation, southwest corner of junction of Mississippi Highway 15 and Interstate 20, behind Texaco Station, just north of Newton, Newton County, Mississippi.

TU 924. Cook Mountain Formation, roadcut 2.7 miles east of Mississippi Highway 15 at Newton, on road to Poplar Springs Church, Newton County, Mississippi.

University of California, Riverside Locality Numbers

UCR 1. Llajas Formation, east of road in Las Llajas Canyon, approx. 2 miles northeast of Marr Ranch on the first ridge northeast of spring at 1650-foot contour and approx. one-half mile due west of hill 2560, Santa Susana 15-minute quadrangle, Ventura County, California.

UCR 1838. Llajas Formation, Member III-2, probably Las Llajas Canyon, Santa Susana Mountains, Ventura County, California.

UCR 4699. Juncal Formation, beds containing *Turritella uvasana applinae* fauna (Givens, 1974), on crest of northwest-trending ridge south of the main fork of Park Canyon, 1600 ft S., 2600 ft E. of NW corner of sec. 13, T. 7 N., R. 22 W., San Guillermo 7.5 minute quadrangle (1943 ed.), Pine Mountain area, Ventura County, California.

UCR 4923. Ardath Shale, near top of unit, at lat. 32° 53′ 33″ N., long. 117° 15′ 5″ W., just below top of sea cliff at south end of Torrey Pines State Park, 335 meters south of the north end of Torrey Pines Scenic Drive, Del Mar 7.5 minute quadrangle (1967 ed.), San Diego County, California.

UCR 7719. Llajas Formation, at elevation of 1475 ft on north side of mouth of small gulley branching west from Las Llajas Canyon at spring between "Las" and "Llajas," 2750 ft south and 380 ft east of NW corner of Sec. 28 (projected), T. 3 N., R. 17 W., Santa Susana 7.5 minute quadrangle (1969 ed.), south slope of Santa Susana Mountains, Ventura County, California.

U. S. Geological Survey Locality Numbers

USGS 12632. Llajas Formation, on north side of the Simi Valley, on the east side of Las Llajas Canyon, 6850 ft South 17.5 East from Bench mark 2165, Santa Susana 15 minute quadrangle, Ventura County, California.

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November 9, 1979

REVIEW

READING THE ROCKS: the story of the Geological Survey of Canada, 1842-1972, by Morris Zaslow. Published by The Macmillan Company of Canada Limited, Ottawa, Canada, 1975, x + 599 pp., illus., ...$20.00

This handsome volume reviews in depth the first one hundred and thirty years of existence of The Geological Survey of Canada. In treating of the founding of the Survey and its early years, the author includes an abbreviated survey of the development of geology in Britain and America. Thus, much unexpected material is to be found within the pages of this book. The text is written in a pleasing style which adds much to its effectiveness and usefulness.

The role of Sir William E. Logan in the pioneer years of the Survey is emphasized and a color portrait of Sir William serves as the frontispiece for the work. The first section detailing the Formative Years is followed by three further sections dealing with the later history of the Survey in significant and thorough fashion. It is both comprehensive and well done.

Reading the Rocks is highly recommended for both geologists and historians of science. At the modest price of this volume, it represents quite a bargain for the interested reader.

—H.C.S.

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REVIEW

THE GEOLOGY AND LANDSCAPES OF NEW JERSEY, by Peter E. Wolfe. Published by Crane Russack, New York, 1977, xii + 351 pp., illustrated, ...$19.50

In the initial chapter of this book, the place of New Jersey in the *New Geology* of *Drifting Continents* is explored, including a brief historical review of *Continental Drift, Seafloor Spreading*, and *Plate Tectonics* concepts. The next four chapters consider the geological history of the New Jersey area Era by Era with the geologic distribution of the rocks of each segment of the geologic past and their structural and geological history. These are followed by chapters on Landscapes, Geomorphic Provinces, Landscapes of the New Jersey Highlands, Landscapes of the Piedmont Lowlands, Landscapes of the Coastal Plain, Coastal Margins and Shorelines, and finally, the Submerged Continental Margin. A glossary and an index are appended.

New Jersey has a remarkably diverse geologic rock column as well as a varied structural and geomorphic history. It provides an excellent vehicle for the novel approach of this work to geological study, and should be of substantial interest to all geologists as well as to those primarily concerned with the geology of New Jersey and environs.

—H.C.S.

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1980-1981

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A. MYRA KEEN

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I. ABSTRACT

The family Cardiidae is here considered to comprise six subfamilies: Cardiinae, Trachycardiinae, Fraginae, Hemidonacinae, Protocardiinae, and Laevicardiinae. The Eurasian brackish-water groups are regarded as a separate family, the Lymnocardiidae. Of 109 nominal taxa assigned to the family, 77 are accepted as useful at the generic or subgeneric levels, and one other is listed but considered of doubtful utility. The family began to emerge during late Triassic time and has radiated widely. In present-day seas cardiids are most abundant on sandy bottoms and in shallow water, although they may occur offshore in depths to 300 meters.

Morphologic differences between the generic units in each of the subfamilies are summarized in dichotomous keys. Insofar as possible illustrations are of the type species for each unit, and figures of shell interiors and hinges are of left valves.

A tabular summary of classification is designed to show distribution of each unit in time and space. Phylogeny of the family can be only sketchily suggested as yet, because of gaps in the fossil record. Strongest relationship seems to be to the superfamily Carditacea.

Some notes on a recent review of the family by Prof. Édouard Fischer-Piette are included in an appendix. A second appendix discusses placement of two new generic units that were published by Robert Scott while this paper was in the editorial office.

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II. INTRODUCTION

In 1935, as a beginner in the study of mollusks, I made a simple observation that led to a lifetime interest in cardiids. Noticing that specimens of "*Cardium corbis*" (as I was then calling it) had prosogyrate beaks, I asked Professor Hubert Schenck, a Stanford University paleontologist, whether this was significant. Missing no chance to stimulate research, he countered by suggesting I try to find out. As any systematist can guess, the answers I found only led to more questions. Before I was through I had started to index all the names of species allocated to *Cardium*. My file now comprises several thousand cards. Like most other Linnean genera, *Cardium* had already begun to be subdivided, and the cluster of generic taxa accorded family status, as the Cardiidae. Before long I felt constrained to propose yet another generic category (Keen, 1936a) for the "*Cardium corbis*" of authors and its close relatives, *i.e.*, *Clinocardium*. This proposal had to be supported by a paper listing other named units in the family (Keen, 1937). Then I began work on a monograph I thought should wrap up my research nicely; yet somehow it would not fall into satisfactory form. The generic key planned as its central feature proved, when tested, to be unworkable. In one sense, the intended synopsis has lain dormant these forty years. In another it has not, for sections have appeared in print (Keen, 1950; 1951; 1954; Keen *in* Moore *et al.*, 1969); and I have had time to test my insights on relationships by extensive study of specimens and literature.

The figures I had prepared to illustrate the groupings I saw as subfamilies still are usable. Perhaps now, with longer experience, I may be able to modify the planned key into more satisfactory form. Indeed, it is time I should elaborate on my conclusions, for competing classifications have recently begun to surface (Kafanov, 1975; Fischer-Piette, 1977; Kafanov & Popov, 1977), and even while this paper was under editorial review two new taxa have been proposed (Scott, 1978), which can be only partially taken into account herein.

Not only was I guided in arriving at a classification of the Cardiidae by Professor Schenck but also by the counsel of other active systematists of that time. In a letter dated Sept. 26, 1936, commenting on a preliminary draft of my intended work, Dr. Wendell Woodring of the U. S. Geological Survey gave some advice that I do not forget: "Workers who spend much time on one family or one genus are likely to get an exaggerated idea of the number of major categories that can be recognized. My treatment of the Turridae [*i.e.*, his paper in 1928 on the Bowden Miocene gastropods of Jamaica] is a fine, or rather, a terrible example. . . I am in favor of narrowly defined categories, but I am not in favor of an indiscriminate boosting of categories to higher ranks."

Dr. Don L. Frizzell was then a graduate student at Stanford University. His counsel is epitomized in a statement on Veneracea (Frizzell, 1936), the group on which he wrote his doctoral thesis. He pointed out that a phylogeny or hypothetical line of succession must not be based upon a single character, such as the hinge, for this ignores the principle of summation of characters; scrutiny of orthogenetic or convergent trends as well as of the ontogenetic development of representative species must be prerequisite to any trustworthy scheme of classification.

Another mentor of that period was Professor Gordon Ferris of the Biology Department of Stanford. I read and re-read his essay on classification (Ferris, 1928) — a philosophy encapsulated in one sentence that he italicized: "*. . the essence of classification is grouping.*" As he said, the tendency should be "to conserve groups rather than to separate them, unless that separation be the separation of *groups*." This is a wholesome about-face from the common practice of saying, "Here is a specimen (or species, or genus, or whatever) that is different; therefore I propose to regard it as a new . . ." Instead, one should say, "Here is a specimen (or species, etc.) that shares a number of traits with these others; therefore I will group them together." Obviously, one must note differences (it is axiomatic that no two living things are exactly alike), but the emphasis should be on relationships and the number of traits in common. Grouping into larger constellations will be on balance, and one is saved having to decide which traits or measurable characters are more important than others.

The classification of Cardiidae took place, naturally, more by dismemberment than by grouping. Although there had been several reviews, such as those of Römer (1868-69), Fischer (1887), and Dall (1901), the first person to begin to try to draw groups together within the family seems to be Stewart (1930), who recognized three subfamilies, Cardiinae, Trachycardiinae, and Fraginae, the latter two of which he proposed as new. I added Laevicardiinae (Keen, 1936b) and Protocardiinae (Keen, 1951). Other nominal categories have been proposed since — Cerastodermatinae Nordsieck, 1969; Hemidonacinae Iredale and McMichael, 1962, as recognized by Boss, 1971; and Clinocardiinae Kafanov, 1975.

The thorny problem of the brackish-water Cardiacea I am deliberately shunting aside. Stoliczka in 1870 had split them off as a subfamily, Lymnocardiinae. During medial Tertiary time a Tethyan-Mediterranean molluscan fauna became isolated in southeastern Europe, in the Euxine Basin area. As the water freshened, marine invertebrates were obliged either to adapt or to die out. The cardiids adapted. Whether the several cardiid stocks then extant — *Cerastoderma, Laevicardium, Parvicardium, Nemocardium,* and *Cardium* s. s. — were able to hybridize or whether the stress released potentialities for immense variation within a single strain among them is a question that no one seems to have attacked. Unfortunately, most of the literature on them is in Russian or other Slavic languages and difficult of access. My studies having been primarily on the marine cardiids, I have not attempted to untangle the web of relationship between these dissociated groups. The brackish-water forms have proliferated through late Tertiary time and still are represented by a number of distinctive species, of which some have long siphons and a pallial sinus, some have thin or almost transparent shells, and some have heavy shells with aberrant hinges. Biochemical studies of the soft parts as well as careful anatomical comparisons with the normal marine stocks would be a fruitful line of study for anyone who is equipped to make such analyses. Meanwhile, it seems preferable to draw an arbitrary dividing line between the main-line and the derived forms. I have, therefore, assigned all of the brackish-water nominal taxa to Lymnocardiidae as a separate family, which I have summarized at more length in the *Treatise on Invertebrate Paleontology* (Keen *in* Moore *et al.*, 1969).

Three papers that are titled as revisions of the Cardiidae have appeared in recent years. The one by Fischer-Piette (1977) gives no rationale for the groupings it effects. No subfamily categories are cited; genera are divided into subgenera and "sections," in a sequence different from that of any other author. Because there is no explanation for these innovations, I see little point in attempting item-by-item commentary, although I have added as an appendix to this paper a summary of the new species Fischer-Piette describes, with notes on the allocations that I would make of these and the species for which he gives figures of type specimens. He seems to put more weight on priority of generic names than on morphological characters of the shells themselves. At least this is the only explanation I can find for the use of *Corculum* Röding, 1798, as the generic name for the West American species assigned to *Clinocardium* Keen, 1936, in modern literature; however, his substitution of *Keenocardium* Kafanov, 1975, as the subgeneric taxon for them instead of *Clinocardium*, under *Corculum*, leaves one puzzled.

The classifications by Kafanov (1975) and Kafanov and Popov (1977) do have an undergirding of descriptive text in Russian. My reluctance to accept especially the Kafanov and Popov classification stems from its having been based upon elaboration of a single character, microstructure of the shell. Although shell structure may well be useful as one of the criteria for grouping, using it exclusively ignores the basic principle of summation of characters. Kafanov and Popov would divide Cardiidae into six subfamilies: Cardiinae, with five tribes and 19 generic taxa; Clinocardiinae, with three tribes and seven genera; Fraginae, with three tribes and 22 genera; Hemidonacinae, one genus; Protocardiinae, for which they mention seven genera that occur in the Tertiary and omit 17 that are mostly of Mesozoic distribution; and Lymnocardiinae, with nine tribes and 71 genera. Although some of their reallocations have plausibility, I cannot accept the use of a single criterion, such as microstructure,

without more exhaustive study of ontogenetic series, of chronogenetic successions, of locus effects (*i.e.*, what part of the shell is sectioned), of habitat effects, and so on. No matter how basic the structural character, one cannot ignore the soft parts, the hinge elements, shell contour, ribbing patterns, surface sculpture, and other variables. Shell microstructure may, in fact, prove to be iterative or progressive, as gill structure has already proved to be in bivalve classification. Newell (*in* Moore *et al.*, 1969, p. N-209) has observed that original shell microstructure rarely is preserved in the earlier bivalve fossils and may even be destroyed in fossils that are geologically rather young; also that there are differences within groups in stability of structure — some may be environmentally modified, others not.

A workable classification, of course, must be based upon morphological characteristics. The implicit assumption is that groups with many observable traits in common are more or less closely related, differentiated through isolation and genetic drift. Observed distribution in time and space should not be a factor to influence judgments on morphology. However, if, after the classification is established, one finds a geographic or geologic coherence in the groups, it is useful confirmatory evidence that a true relationship exists and that distribution reflects past dispersal pathways. A classification that does not examine both the morphologic bases and the distribution risks being superficial.

In general, I have been satisfied that distributional patterns did support my subdivisions of cardiid groups. While preparing the index cards, I was also making tentative allocations of the nominal species. When these were summarized, I found that distributions were homogeneous, with few exceptions, as indicated in Section 3 of this paper.

III. ACKNOWLEDGMENTS

Several of those to whom I am indebted for help during the forty years that this paper has been generating no longer are living — notably Professor Hubert G. Schenck, Stanford University; Dr. Don L. Frizzell (then a Stanford student); and David Vernon, a local amateur. Others, such as Dr. Wendell Woodring of the U. S. Geological Survey and Dr. Hollis Hedberg, probably have forgotten that at one time they had been asked for advice and had given useful suggestions. I owe much also to the many correspondents who replied to letters of inquiry and loaned or gave material. A German paleontologist, for example — Dr. W. O. Dietrich — not having an extra reprint that I needed, sent me his proof sheets and original photographs, from which I now have been able to reconstruct a hinge hitherto unillustrated. A number of competent artists have lent their skill to making the line drawings, especially E. H. Quayle in the 1930s, Jeanne Janish in the 1940s, and Perfecto Mari in more recent years. Philip Palmer has helped me on reallocation of some Mesozoic units. Ellen J. Moore of the U. S. Geological Survey and Dr. Robert Robertson of the Academy of Natural Sciences, Philadelphia, have supplied needed reference material. To Dr. Eugene Coan I owe thanks not only for critical reading of the manuscript but also for his encouragement toward my completion of this long-unfinished report, and Sandra Gardner has read some parts of the text. To all these people goes my deep appreciation for their help.

I acknowledge, with thanks, permission from the editors of the *Treatise on Invertebrate Paleontology* to reprint illustrations published as a part of my revision of Cardiacea in that work.

IV. FORMAT

The plan of the present work is as follows: Section 1 is an alphabetical listing of all the marine cardiid generic-level taxa that I have been able to discover in the literature, with notes on original references (except for those few that are invalid because of primary homonymy); the name of the type species; manner of designation; and synonyms. An asterisk is used to avoid the repetition of the words "type species" (in the style of the *Treatise on Invertebrate Paleontology*). The standard symbols for manner of type designation are explained under "Abbreviations," in the final pages of this paper. Names accepted as valid and usable are written in capitals; synonyms and nomenclaturally invalid names are in italics. The number at the end of each entry refers to the placement of the unit in the formal classification of Section 3. Synonyms are indicated by square brackets, the enclosed

number being that of the unit under which they are presumed to fall.

Section 2 comprises keys to the generic units within each of the subfamilies recognized. A single key to all the genera proved to be unworkable because no one character can be found that without exception will subdivide the major groupings; instead, grouping must be arrived at on the basis of summation of characters. To use the keys one makes judgments of the general relationships of the shell in hand either by scanning the introductory paragraphs for each of the separate keys or by use of Table 1, an analytical summary of the principal characters of the cardiid shell. This table attempts to show the incidence of each trait, whether common to the entire subfamily or present only in a few of the generic units. The plates are grouped, insofar as practicable, according to subfamily, which may also help in narrowing choices. For the novice who does not already have a working idea of relationships of the shells being keyed, the multiple keys are, I admit, an obstacle to quick determinations. A process of trial and error — trying first the table, then, if no clear choice emerges, one key after another, checking with the given figures to assess plausibility — will build up gradually the skill needed to start immediately into the proper key. For experience there is no ready substitute.

Could one have only a single view of a cardiid shell, the best choice would be the interior of he left valve, for the right hinge is complicated by some degree of fusion of the cardinal teeth. The left valve interior shows not only the construction of the hinge but reveals much about the shape of the shell, the strength of the ribs, and their relative distribution. This view is the one selected for the line drawings that I had prepared especially for this work. Figures of exteriors also are included here, mostly copied from literature. In the keys, numbers in square brackets following the names of the keyed generic units refer to the placement in the classification of Section 3.

The formal classification of the Cardiidae resulting from my studies of the family comprises Section 3. Here each nominal taxon that is considered useful is numbered in sequence. Distribution in time and space is summarized, and reference is made to the illustrations. The figures are, with minor exceptions, those of the type species. Only when no good figures of the hinge of the type species could be obtained were substitutions made — hinges of presumably representative species. A few good figures of typical sculpture also are representative rather than type species, but in every case these are clearly indicated as not type species.

Lastly, Section 4 is an outline of the phylogeny of Cardiidae as I have been able to construe it from my studies of the literature and of material in several large museum collections.

Section 1: Generic units of the Cardiidae

Taxon number, in section 3

ACANTHOCARDIA Gray, 1851. List of specimens . . British Mus., Pt. VII, p. 23. **Cardium aculeatum* Linné, 1758; SD, Stoliczka, 1870, p. 207. Syn.: *Archicardium; Eucardium; Orbis; Sphaerocardium* 4

Acanthocardium Römer, 1868 (?1865). Syst. Conch. Cab., ed. 2, vol. 10, pt. 2, Cardiacea, p. 17. **Cardium aculeatum* Linné, 1758; SD, Tryon, 1869, p. 60 .....[4]

ACROSTERIGMA Dall, 1900. Trans. Wagner Free Inst. Sci., vol. 3, pt. 5, p. 1073. **Cardium dalli* Heilprin, 1887; OD 27

Africofragum Eames, 1957. Bull. British Mus. (Nat. Hist.), Geol., vol. 3, no. 2, p. 61. **Fragum (A.) newtoni* Eames, 1957; OD. = *Schedocardia*. .....[8]

AFROCARDIUM Tomlin, 1931. Ann. Natal Gov. Mus., vol. 6, pt. 3, p. 449. **Fragum (A.) shepstonense* Tomlin, 1931; OD. 36

AGNOCARDIA Stewart, 1930. Spec. Publ. Acad. Nat. Sci. Phila., vol. 3, p. 37, 264. **Cardium claibornense* Aldrich, 1911; OD. . .5

AMERICARDIA Stewart, 1930. *Ibid.*, p. 37, 267. **Cardium medium* Linné, 1758; OD. 39

Amphicardium Von Martens, 1880, *in* Möbius, Beiträge zur Meeresfauna Mauritius, p. 324. **Cardium lyratum* Sowerby, 1841; SD, Keen, 1937, p. 5. = *Lyrocardium*. .....[61]

Aphrodite Lea, 1834 (*non* Hübner, 1816). = *Serripes*. .....[76]

APIOCARDIA Olsson, 1961. Panama-Pacific Pelecypoda, p. 252. **Cardium obovale* Sowerby, 1833; OD. 40

Archicardium Sandberger, 1863. Conchylien des Mainzer Tertiärbeckens, p. 317. **Cardium aculeatum* Linné, 1758; SD, Keen, 1937, p. 5. = *Acanthocardia*. .....[4]

ARCTOPRATULUM Keen, 1954. Bulls. Amer. Paleont., vol. 35, no. 153, p. 317. **Nemocardium (A.) griphus* Keen, 1954; OD. 54

Awadia Abbass, 1962. United Arab Repub. Min. Industry, Geol. Survey, Geol. Mus., Pal. Ser., Monog. 1, p. 128. **Nemocardium (A.) magharense* Abbass, 1962 (as *magharensis*); OD. = *Nemocardium*. .....[53]

BREVICARDIUM Stephenson, 1941. Univ. Texas Publ. no. 4101, p. 203. **B. fragile* Stephenson, 1941; OD. 43

BUCARDIUM Gray, 1853. Ann. Mag. Nat. Hist., (ser. 2) vol. 11, p. 40. **Cardium ringens* "Chemn.," i.e., Bruguière, 1789; SD, Von Vest, 1875, p. 323. Syn.: *Ringicardium*. 2

Cardea Whitfield, 1885. U. S. Geol. Surv. Monog. 9, p. 134, note. **Cardium dumosum* Conrad, 1870; M. = *Criocardium*. .....[10]

Cardiarius Duméril, 1806. Zool. Analytique, p. 333. **Cardium edule* Linné, 1758; SM, Fröriep, 1806, p. 83. = *Cerastoderma*. ....[70]

Cardissa Megerle von Mühlfeldt, 1811 Ges. Nat. Fr. Berlin, Mag., Vol. 5, p. 52. **C. alba* Meg. V. Mühlfeldt, 1811 = *Cardium cardissa* Linné, 1758; M. = *Corculum*. .....[34]

CARDIUM Linné, 1758. Systema Naturae, p. 678. **C. costatum* Linné, 1758; SD, Children, 1823, p. 315. Syn.: *Cordium; Tropidocardium*. 1

Cerastes Poli, 1795 (*non* Laurenti, 1768). = *Cerastoderma*. .....[70]

CERASTODERMA Poli,1795. Test. utriusque Sicil., vol. 2, p. 252, 258. **Cardium edule* Linné, 1758; SD Von Martens, 1870, p. 586. Syn.: *Cerastes; Cardiarius; Edulicardium*. 70

CILIATOCARDIUM Kafanov, 1974. Zool. Zh. Akad. Nauk, SSSR, vol. 53, no. 10, p. 1469. **Cardium ciliatum* Fabricius, 1780; OD. ...72

CLINOCARDIUM Keen, 1936. Trans. San Diego Soc. Nat. Hist., vol. 8, no. 17, p. 119. **Cardium nuttallii* Conrad, 1837; OD. ?Syn.: *Keenocardium*. 71

CONILOCARDIUM H. Vokes, 1977. Tulane Stud. Geol. Paleont., vol. 13, no. 4, p. 157. **Cardium cestum* Dall, 1900; OD. 23

Cor Mörch, 1852. Catal. conchyl. Yoldi, p. 36. [Not validly proposed — cited only in synonymy.] = *Corculum*. .....[34]

CORCULUM Röding, 1798. Museum Boltenianum, p. 188. **Cardium cardissa* Linné, 1758; SD Von Martens, 1870, p. 586. Syn.: *Cardissa; Cor; Cordissa; Hemicardia*. 34

Cordissa Gistel, 1848. Naturges. Thier., p. xiv. [Emendation] = *Corculum*. .....[34]

Cordium Gistel, 1848. *Ibid.*, p. xiv. [Emendation] = *Cardium*. .....[1]

CRIOCARDIUM Conrad, 1870. Amer. Jour. Conch., vol. 6, p. 75. **Cardium (C.) dumosum* Conrad, 1870; SD Stoliczka, 1871, p. 486. Syn.: *Cardea; Criocarpium*, spelling error. 10

CRYPTOCARDIA Palmer, 1974. Palaeontology, vol. 17, no. 1, p. 168. **C. bajocensis* Palmer, 1974; OD. 44

CTENOCARDIA H. & A. Adams, 1857. Genera Rec. Moll., vol. 2, p. 459. **Cardium hystrix* Reeve, 1844 (*non* Lightfoot, 1786) = *Fragum symbolicum* Iredale, 1929; SD, Dall, 1900. ..35

DALLOCARDIA Stewart, 1930. Spec. Publ. Acad. Nat. Sci. Phila., no. 3, p. 37, 264. **Cardium quadragenarium* Conrad, 1837; OD. ..24

Decussicardium Fischer-Piette, 1977. Mem. Mus. Natl. d'Hist. Nat., (n.s.) Ser. A, Zool., vol. 101, p. 94. [*Nomen nudum;* no type species designated; no generic diagnosis or discussion].

DINOCARDIUM Dall, 1900. Trans. Wagner Free Inst. Sci., vol. 3, pt. 5, p. 1074. *"*Cardium magnum* Born, 1778" (*non* Linné, 1758) = *C. robustum* [Lightfoot], 1786; OD. Syn.: *Exocardium*. 67

DISCORS Deshayes, 1858. Anim. s. vert. Bassin Paris, vol. 1, p. 553, 569. **Cardium discors* Lamarck, 1805 (*non* Montagu, 1803) = *C. parisiense* Orbigny, 1850; T. Syn.: *Hemidiscors*. 55

DIVARICARDIUM Dollfus & Dautzenberg, 1886. Feuille Jeunes Natural., 16me Ann., no. 188, p. 95. **Cardium discrepans* Basterot, 1825; SD, Cossmann, 1886, p. 175. 56

DOCHMOCARDIA Scott, 1978. Jour. Paleont., vol. 52, no. 4, p. 894. **Cardium pauperculum* Meek, 1871; OD. [*See* Appendix II]

Donacicardium Von Vest, 1875. Jahrb. mal. Ges., vol. 2, p. 322; OD. Syn.: *Donaciocardium*, emend. = *Hemidonax*. .....[41]

Edulicardium Monterosato, 1923. R. Comitato Talass. Ital., Mem. 107, p. 4. **Cardium edule* Linné, 1758; M. = *Cerastoderma*. .....[70]

ETHMOCARDIUM White, 1880. Proc. U. S. Natl. Mus., vol. 2, p. 291. **Cardium speciosum* Meek & Hayden, 1857 (*non* Adams & Reeve, 1850) = *C. whitei* Dall, 1900; OD. 11

Eucardium Fischer, 1887. Man. Conchyl., p. 1037. **Cardium aculeatum* Linné, 1758; SD, Stewart, 1930. = *Acanthocardia*. .....[4]

EUROPICARDIUM Popov, 1977. Trans. Paleont. Inst. SSSR, vol. 153, p. 44 [*Nom. nud.*, Popov, 1974]. **Cardium multicostatum* Brocchi, 1814; OD. 6

Exocardium Olsson, 1964. Neogene moll. Northwestern Ecuador, p. 55. **Cardium ecuadoriale* Olsson, 1932 (as *ecuadorialis*); OD. = *Dinocardium*. .....[67]

FRAGUM Röding, 1798. Museum Boltenianum, p. 189. *F. *flavum* Röding, 1798 = *Cardium fragum* Linné, 1758; T. Syn.: *Hemicardium; "Hemicardia* Spengler" of authors. 32

FRIGIDOCARDIUM Habe, 1951. Genera Japanese Shells: Pelecypoda, no. 2, p. 152. **Cardium eos* Kuroda, 1929; OD. Syn.: *Erigidocardium*, spelling error. 57

FULVIA Gray, 1853. Ann. Mag. Nat. Hist., (ser. 2) vol. 11, p. 40. **F. aperta* [Bruguière] = *Cardium apertum* Bruguière, 1789; M. 68

FUSCOCARDIUM Oyama, 1973. Palaeont. Soc. Japan, Spec. Pap., no. 17, p. 100. **Cardium braunsi* Tokunaga, 1906; OD. 73

GLOBOCARDIUM Hayami, 1965. Mem. Fac. Sci. Kyushu Univ., ser. D, Geol., vol. 17, no. 2, p. 116. **Cardium sphaeroideum* Forbes, 1845; OD. 45

GRANOCARDIUM Gabb, 1869. Geol. Survey Calif., Paleont., vol. 2, p. 266. **Cardium carolinum* Orbigny, 1844; SD, Stewart, 1930, p. 264. 9

HABECARDIUM Glibert & Van de Poel, 1970. Mém. Inst. Roy. Soc. Natl. Hist. Belgique, (ser. 2) fasc. 84, p. 34. **Cardium tenuisulcatum* Nyst, 1836; OD. 58

Hassbergia Krumbeck, 1939. Sitzber. phys.-mediz. Soz. Erlangen, vol. 71, p. 46. [Invalidly proposed; no type designation.] = *Protocardia*. . . . . .[42]

HEDECARDIUM Marwick, 1944. Trans. Roy. Soc. New Zealand, vol. 74, pt. 3, p. 260. **Cardium waitakiense* Suter, 1907; OD. . . .20

Hemicardia Fleming, 1818. Encycl. Brit., Suppl. vols. 4-6, p. 304.**Cardium cardissa* Linné, 1758; M. [Earlier usage of *Hemicardia* by Spengler, 1799 was not at a generic but at a group level, as an informal term; the "*Hemicardia* Spengler" of authors is here considered a synonym of *Fragum*.] = *Corculum*. . . . . .[34]

Hemicardium Schweigger, 1820. Handb. Naturg., p. 707. **Cardium cardissa* Linné, 1758; M. = *Corculum*. . . . . .[34]

Hemidiscors Rovereto, 1898. Atti Soc. Ligustica, vol. 9, p. 181. **Cardium rugiferum* Rovereto, 1898; OD. = *Discors*. . . . . .[55]

HEMIDONAX Mörch, 1870. Malak. Bl., vol. 17, p. 121. **Donax pictus* Tryon, 1870, = *Cardium donaciforme* Bruguière, 1792 [cited by Boss, 1971, as of Schroeter, 1786; a non-binomial work, *fide* Sherborn, *Index Anim.*, vol. 1, 1902]; M. Syn.: *Donacicardium*. 41

INCACARDIUM Olsson, 1944. Bulls. Amer. Paleont., vol. 28, no. 111, p. 211. **Cardium (I.) mellisum* Olsson, 1944; OD. 12

INTEGRICARDIUM Rollier, 1912. Mém. Soc. Pal. Suisse [=Abh. Schweiz Pal. Ges.], vol. 38, p. 127. **Cardium dupinianum* Orbigny, 1844; OD. 50

JURASSICARDIUM Cossmann, 1906. Compt.-Rend. Assoc. Franç. Avanc. Sci., vol. 34, p. 294. **Cardium (J.) axonense* Cossmann, 1906; M. [sole species eligible for designation; SD Keen, 1937]. 52

Kathocardia Tucker & Wilson, 1932. Bulls. Amer. Paleont., vol. 18, no. 65, p. 44. **Cardium (K.) aclinense* Tucker & Wilson, 1932 (as *aclinensis*); OD. = *Trachycardium*. . . . . .[22]

KEENAEA Habe, 1951. Genera Japanese Shells: Pelecypoda, no. 2, p. 152. **Cardium samarangae* Makiyama, 1934; OD. 59

?KEENOCARDIUM Kafanov, 1974. Zool. Zh. Akad. Nauk, SSSR, vol. 53, no. 10, p. 1468. **Cardium californiense* Deshayes, 1839; OD. [Of doubtful utility; probably = *Clinocardium, s.s.*, although named as a subgenus.]. . . . . .[74]

[KOROBKOVIELLA] Merklin, 1974. Trans. Palaeont. Inst., vol. 145, p. 97. **Cerastoderma (K.) kiktenkoi* Merklin, 1974; OD. [Reallocated to Lymnocardiinae by Popov, 1977, p. 77].

LAEVICARDIUM Swainson, 1840. Treatise Malac., p. 373. **Cardium oblongum* "Chemn.," i.e., Gmelin, 1791; SD, Stoliczka, 1871, p. xviii. Syn.: *Levicardium; Liocardium; Loevicardium*, emendations. 66

LEPTOCARDIA Meek, 1876. U. S. Geol. Surv. Terr., vol. 9, p. 172. **Cardium subquadratum* Evans & Shumard, 1857; SD, Dall, 1901, p. 385. 46

LOPHOCARDIUM Fischer, 1887. Man. Conchl., p. 1038. **Cardium cumingii* Broderip, 1833; M. 60

LOXOCARDIUM Cossmann, 1886. Ann. Soc. Roy. Malac. Belgique, vol. 21, p. 172. **Cardium formosum* Deshayes, 1858; SD, Crosse, 1887, p. 332. 13

LUNULICARDIA Gray, 1853. Ann. Mag. Nat. Hist., (ser. 2) vol. 11, p. 41. **L. retusa*, i.e., *Cardium retusum* Linné, 1767; M. Syn.: *Opisocardium*. 33

LYROCARDIUM Meek, 1876. U. S. Geol. Surv. Terr., vol. 9, p. 173. **Cardium lyratum* Sowerby, 1841; SD, Dall, 1900, p. 1076. Syn.: *Amphicardium*. 61

MAORICARDIUM Marwick, 1944. Trans. Roy. Soc. New Zealand, vol. 74, pt. 3, p. 263. **Cardium spatiosum* Hutton, 1873; OD. 16

MEXICARDIA Stewart, 1930. Spec. Publ. Acad. Nat. Sci. Phila., no. 3, p. 37, 263. **Cardium procerum* Sowerby, 1833; OD. 25

MICROCARDIUM Thiele, 1934. Handb. Syst. Weichtierk., pt. 3, p. 878. **Cardium peramabile* Dall, 1881 (as *peramabilis*); SD, Keen, 1937, p. 15. 62

MICROFRAGUM Habe, 1951. Genera Japanese Shells: Pelecypoda, no. 2, p. 148. **Cardium festivum* Deshayes, 1854; OD. 37

NEMOCARDIUM Meek, 1876. U. S. Geol. Surv. Rept., vol. 9, p. 167. **Cardium semiasperum* Deshayes, 1858; SD, Sacco, 1899, p. 56. Syn.: *Awadia*. 53

ONESTIA McLearn, 1933. Trans. Roy. Soc. Canada, (ser. 3) vol. 27, pt. 4, p. 152. **Laevicardium onestae* McLearn, 1931; OD. 51

Opisocardium Bayle, 1879. Jour. Conchyl., vol. 27, p. 35. **Cardium retusum* Linné, 1767; OD. = *Lunulicardia*. . . . . .[33]

Orbis Blainville, 1825 (*non* Müller, 1767). = *Acanthocardia*. . . . . .[4]

ORTHOCARDIUM Tremlett, 1950. Proc. Malac. Soc. London, vol. 28, p. 128. **Cardium porulosum* Solander, 1766; OD. 3

OVICARDIUM Marwick, 1944. Trans. Roy. Soc. New Zealand, vol. 74, pt. 3, p. 268. **Trachycardium (O.) rossi* Marwick, 1944; OD. 28

PACHYCARDIUM Conrad, 1869. Amer. Jour. Conch., vol. 5, p. 96. **Cardium spillmani* Conrad, 1858; SD, Dall, 1900, p. 1076. 47

PAPILLICARDIUM Sacco, 1899. I Molluschi terr. terz. Liguria, pt. 27, p. 44. **Cardium papillosum* Poli, 1795; OD. 17

PAPYRIDEA Swainson, 1840. Treat. Malac., p. 374. **Cardium soleniforme* Bruguière, 1789; SD, Gray, 1847, p. 185 30

PARVICARDIUM Monterosato, 1884. Nomencl. gen. e spec. medit., p. 19. **Cardium parvum* Philippi, 1844 (*non* Da Costa, 1778) = *C. exiguum commutata* Bucquoy, Dautzenberg, & Dollfus, 1892; SD, Crosse, 1885, p. 140 14

Pascoella Cox, 1949. Bull. Inst. Geol. Peru, no. 12, p. 33. **P. peruviana* Cox, 1949; OD. = *Septocardia*.....[18]

Pectunculus Mörch, 1853 (*non* Da Costa, 1778). = *Vepricardium*.....[19]

PERUCARDIA Olsson, 1944. Bulls. Amer. Paleont., vol. 28, no. 111, p. 209. **Cardium (P.) brueggeni* Olsson, 1944; OD. 21

PHLOGOCARDIA Stewart, 1930. Spec. Publ. Acad. Nat. Sci. Phila., no. 3, p. 38, 263. **Cardium belcheri* Broderip & Sowerby, 1829; OD. 26

PLAGIOCARDIUM Cossmann, 1886. Ann. Soc. Roy. Malac. Belgique, vol. 21, p. 168. **Cardium granulosum* Lamarck, 1805; SD, Crosse, 1887, p. 332.....15

PLANICARDIUM Olsson, 1967. Some Tertiary mollusks . . Caribbean, p. 11. **Cardium virginianum* Conrad, 1839; OD. 75

PLEURIOCARDIA Scott, 1978. Jour. Paleont., vol. 52, no. 4, p. 893. **Cardium kansasense* Meek, 1871; OD. [*See* Appendix II]

PRATULUM Iredale, 1924. Proc. Linn. Soc. N. S. Wales, vol. 49, p. 182. **Cardium thetidis* Hedley, 1902; OD. 63

PROFULVIA Kafanov, 1976. Paleontol. Zh., SSSR, no. 4, p. 111. **Papyridea harrimani* Dall, 1904; OD. 69

PROTOCARDIA Von Beyrich, 1845. Zeit. f. Malak., vol. 2, p. 17. **Cardium hillanum* J. de C. Sowerby, 1813; SD, Herrmannsen, 1847, p. 336. Syn.: *Protocardium*, invalid emendation; *Hassbergia*. 42

REGOZARA Iredale, 1936. Rec. Australian Mus., vol. 19, no. 5, p. 275. **R. olivifer* Iredale, 1936; OD. 29

Ringicardium Fischer, 1887. Man. Conchyl., p. 1037. **Cardium ringens* "Chemn.," i.e., Bruguière, 1789; M. = *Bucardium*. .....[2]

RUDICARDIUM Coen, 1915. Ann. Mus. Civico Storia Nat. Genova, vol. 46, p. 299. **Cardium tuberculatum* Linné, 1758; SD, Keen, 1937, p. 17. 7

SCHEDOCARDIA Stewart, 1930. Spec. Publ. Acad. Nat. Sci. Phila., no. 3, p. 38, 255. **Cardium hatchetigbeense* Aldrich, 1886; OD. Syn.: *Africofragum*. 8

SEPTOCARDIA Hall & Whitfield, 1877. Rept. U. S. Geol. Surv. Explor. Exped. 40th Parallel, vol. 4, p. 294. **S. typica* Hall & Whitfield, 1877; OD. Syn.: *Pascoella*. 18

SERRIPES Gould, 1841. Invert. of Massachusetts, p. 93. **Cardium groenlandicum* Bruguière, 1789; M. Syn.: *Aphrodite; Yagudinella* 76

Sphaerocardium Coen, 1933. Mus. Com. Talass. Ital., Mem. no. 192. p. 132. **Cardium paucicostatum* Sowerby, 1841 (*non* Deshayes, 1838); SD, Keen, 1937. Syn.: *Sphoerocardium*, spelling error. = *Acanthocardia*. .....[4]

TENDAGURIUM Dietrich, 1933. Palaeontographica, Suppl. 7, Reihe 2, Teil 2, Lief. 1, p. 50. **Cardium (T.) propebanneianum* Dietrich, 1933; SD, Salisbury, 1934, p. 103. 48

TRACHYCARDIUM Mörch, 1853. Catal. conchyl. Yoldi, p. 34. **Cardium isocardia* Linné, 1758; SD, Von Martens, 1870, p. 586. Syn.: *Kathocardia*. 22

TRIFARICARDIUM Habe, 1951. Genera Japanese Shells: Pelecypoda, no. 2, p. 152. **T. nomurai* Habe, Sept., 1951, *ex* Kuroda & Habe MS, June, 1951 64

TRIGONIOCARDIA Dall, 1900. Trans. Wagner Free Inst. Sci., vol. 3, pt. 5, p. 1075. **Cardium graniferum* Broderip & Sowerby, 1829; OD. 38

Tropidocardium Römer, 1868 (?1865). Syst. Conch. Cab., ed. 2, vol. 10, pt. 2, Cardiacea, p. 13. **Cardium costatum* Linné, 1758; SD Tryon, 1869, p. 60. Syn.: *Tropicardium*, emend.; = *Cardium, s.s*.....[1]

[Tulongocardium] "Chen, J.Chen, & Zhang," *in* Wen Shi-xuan *et al.*, 1976. Rept. Sci. Exped. Mount Jolmo Lungma Region Palaeont., Fasc. 3, p. 31. **Cardium (T.) pluriradiatum* "Chen, Chen, & Zhang" in Wen Shi-xuan *et al.*, 1976; OD. [Probably not cardiid; ?= *Tutcheria* Cox, in Astartacea.]

VARICARDIUM Marwick, 1944. Trans. Roy. Soc. New Zealand, vol. 74, pt. 3, p. 266. **Cardium patulum* Hutton, 1873; OD. 65

VASTICARDIUM Iredale, 1927. Rec. Australian Mus., vol. 16, p. 75. *"*Cochlea nebulosa* Martyn," =*Cardium elongatum* Bruguière, 1789; OD. 31

VEPRICARDIUM Iredale, 1929. Australian Zool., vol. 5, p. 338. **V. pulchricostatum* Iredale, 1929; OD. Syn.: *"Pectunculus"*. 19

Yagudinella Kafanov, 1975. [Investigations of Mollusks, 5th Meeting], Zool. Inst., Akad. Nauk, SSSR, p. 147. **Cardium notabile* Sowerby III, 1915; OD. =*Serripes*. 76

YOKOYAMAINA Hayami, 1958. Japanese Jour. Geol. Geogr., vol. 29, p. 24. **Cyrena elliptica* Yokoyama, 1904 (*non* Dunker, 1843), =*Y. hayamii* Keen & Casey *in* Moore, *et al.*, 1969; OD. [Originally allocated to the Arctici-

dae by Hayami; reassigned, with new evidence, to Cardiidae by Hayami, 1972 (Geol. & Paleont. of Southeast Asia, vol. 10, p. 204, pl. 38, figs. 10-11)].....49

Section 2: Keys to the generic units within Subfamilies

FAMILY CARDIIDAE

Diagnosis of family:

Shells: Equivalve, usually tumid, with well developed radial sculpture; posterior slope normally set off from central and anterior slopes by an umbonal ridge or angle or by a change in ribbing pattern; ligament parivincular, external, mostly short; hinge with two conical cardinal teeth, of unequal size in left valve, somewhat fused in right, arrangement of cardinal teeth in many cruciform (*i.e.*, interlocking in the form of a cross); lateral teeth distant from cardinals, normally one anterior and one posterior in left valve, two anterior and one posterior in right valve (wanting in some groups); adductor muscle scars subequal; pallial line entire in most.

Soft parts: Foot elongate, geniculate (sickle-shaped) in all but one group (see Plate 3, figure 1); siphons short, not markedly extensile or retractile, not having any elaborate siphonal retractor muscle connections; adductor muscles subequal; mantle gape extensive, from the area of the incurrent aperture to the anterior adductor muscle; pallial eyes and pedal-byssal groove present in most; gills plicate, the axis generally dorso-ventrally skewed, with both inner and outer demibranchs.

Distribution: worldwide, greatest abundance in the tropics; also occurring in cold-temperate seas, mainly in shallow water on sandy shores, in sand or sandy mud, shallowly burrowing; some groups offshore in depths to 300 m.

SUBFAMILY CARDIINAE

Shells tumid to inflated, outline mostly equilateral or nearly so; ribs well developed, symmetrical, characteristically sculptured along the rib midline by a spinose or nodose thread or by a groove; posterior margin usually notched by rib ends; interspaces between ribs often with concentric striae; hinge long, hinge teeth nearly in a straight line (*i.e.*, a line joining lateral teeth would bisect the cardinals or be bent less than 25°); cardinal teeth subequal in size, tending to be twisted in left valve or even to lie horizontally one above the other.

Key to generic units

[Taxon number, in section 3]

1. With a large posterior gape ..... CARDIUM s.s. [1]
   Posterior gape small, or posterior end tightly closed 2
2. Posterior ribs prolonged (digitate), interlocked .....BUCARDIUM [2]
   Posterior ribs notching margin but not digitate 3
3. Ribs of two sizes: *i.e.*, intercalary riblets present 4
   Ribs without any intercalary riblets between main ribs 5
4. Intercalaries two to three in number ..... GRANOCARDIUM [9]
   With only one, usually spinous, intercalary CRIOCARDIUM (in part) [10]
5. Valve interior pitted in the inter-rib spaces .....ETHMOCARDIUM [11]
   Interior not pitted 6
6. A deep cavity below hinge for lodgment of the anterior adductor muscle ..... SEPTOCARDIA [18]
   No deep cavity below anterior part of hinge 7
7. Outline somewhat inequilateral, *i.e.*, trapezoidal or oblique-elliptical 8
   Outline nearly equilateral 13
8. Shells small, adults mostly less than 15 mm long 9
   Shells medium-sized to large, more than 15 mm long 10
9. Hinge weak, cardinal teeth minute; ribs with spines or prickles..PARVICARDIUM [14]
   Hinge with well-developed cardinal teeth; ribs with rounded beads ..... PAPILLICARDIUM [17]
10. Trapezoidal; sculpture of spines or nodes .11
    Ovate; sculpture of regular beads 12
11. Rib sculpture well developed, often with spines .....ACANTHOCARDIA [4]
    Rib sculpture irregular, of low scales or absent anteriorly .....SCHEDOCARDIA [8]
12. Shells medium-sized; cardinal teeth about midway between laterals ..... PLAGIOCARDIUM [15]
    Shells mostly large-sized; anterior section of hinge shorter than posterior ..... MAORICARDIUM [16]
13. Ribs ornamented with well-spaced A-shaped, non-imbricate scales or nodes ..... AGNOCARDIA [5]
    Ribs not with A-shaped nodes 14
14. Hinge relatively short (about ½ length of shell) 15

Hinge relatively long (more than ½ length of shell) 17
15. Posterior area set off by a sinuous ventral margin.....INCACARDIUM [12]
Posterior area not set off ventrally by a sinuosity 16
16. Ribs numerous (usually more than 60) EUROPICARDIUM [6]
Ribs less numerous (about 35 to 55) LOXOCARDIUM [13]
17. Ribs with rounded nodes along central furrow 18
Ribs either with spines or nearly smooth . .19
18. Interspaces between ribs narrow ..... PERUCARDIA [21]
Interspaces as wide as ribs ..... RUDICARDIUM [7]
19. Sculpture of ribs spinose 20
Ribs nearly smooth except for a faint central groove 21
20. Hinge plate meeting posterior and anterior margins at a right angle ..... ORTHOCARDIUM [3]
Hinge plate rounding into posterior and anterior margins .....VEPRICARDIUM [19]

Table 1. Salient characters of cardiid subfamilies

++: Present in all generic taxa (genera or subgenera)
x: Present in many or most generic taxa
o: Present in only a few taxa

	Cardiinae	Fraginae, Hemidonacinae	Trachycardiinae	Protocardiinae	Laevicardiinae
POSTERIOR MARGIN					
Notched	x	x	++	x	
Wavy	o	o			++
Smooth (may be crenulate within)				o	x
POSTERIOR SLOPE					
More strongly ribbed than rest of shell				x	
Less strongly ribbed than rest of shell		o		o	++
Equally strong ribbed	x	x	++	o	o
Smooth				o	x
OUTLINE					
Quadrate			x	x	
Elliptical-ovate	x	o	x	x	x
Trigonal	o	x		o	
Trapezoidal	x	o		x	x
RIB SURFACES					
Smooth or unsculptured	x	o	o	x	o
With raised cross-threads		x	x	x	x
Nodose	x				
Spinose	x	x	x	x	
RIB INTERSPACES					
Smooth, with growth lines only	x	o	x	x	x
With raised to ladder-like cross-striae	x	x		o	
Spinose	o		o		
HINGE					
Short, ½ or less shell length	o	x	++	o	
Long, more than ½ length	x			x	
Straight, deflection mostly less than 25°	++		x	x	
Angulate to arched, deflection more than 25°		++	x	x	++
Relatively wide, teeth strong and solid		x	x	x	
Relatively narrow, teeth thin to blade-like	x				x

21. Shell medium-sized to large; interspaces between ribs wide .HEDECARDIUM [20]
    Shell relatively small, interspaces narrow to linear .....CRIOCARDIUM (in part) [10]

SUBFAMILY TRACHYCARDIINAE

Mostly asymmetrical or inequilateral shells; ribs asymmetrical in cross section, well developed throughout shell; spines or other sculpture on ribs usually stronger on posterior edges of ribs; posterior margin notched or even digitate; hinge relatively short, usually less than one-half length of shell, the hinge plate wide in most, cardinal teeth unequal, posterior cardinal in left valve slender.

Key to Generic Units

1. Shell with a posterior gape PAPYRIDEA [30]
   Posterior margins of shell in contact or separated by no more than a chink 2
2. Height and length nearly equal; sculpture, especially along posterior sides of ribs, thorn-like. .....DALLOCARDIA [24]
   Height greater than length; sculpture various but not of thorn-like spines on posterior edges of ribs 3
3. Rib ornamentation of beads and imbricate or overlapping hollow scales .....
   TRACHYCARDIUM [22]
   Rib ornamentation not of hollow scales 4
4. Ribs triangular in cross section 5
   Ribs rounded to rectangular in cross section 6
5. Shell heavy for its size ...MEXICARDIA [25]
   Shell not markedly heavy for its size .....
   CONILOCARDIUM [23]
6. Rib ornamentation of knobbed frills along sides, especially on central slope .....
   PHLOGOCARDIA [26]
   Rib ornamentation not of knobbed frills 7
7. Hinge plate with an oblique groove behind posterior cardinal tooth .....
   OVICARDIUM [28]
   Hinge plate flat behind posterior cardinal tooth 8
8. Hinge sharply bent to an angle greater than 60°; ribs nearly smooth .....
   ACROSTERIGMA [27]
   Hinge angle not more than 60°; ribs with wrinkles or scales, especially along eaves 9
9. Ribs relatively numerous (more than 30) .....
   VASTICARDIUM [31]
   Ribs usually fewer than 30 ..REGOZARA [29]

SUBFAMILY FRAGINAE

Shell inequilateral in outline; umbonal ridge strong in most; posterior margin meeting ventral margin at a 90° angle or less; ribs equally emphasized throughout, intercostal spaces with concentric striations, an intritacalx (chalky surface layer) present in most well-preserved specimens; posterior margin usually notched; hinge relatively short, angulate (*i.e.*, anterior and posterior sections meeting at a sharp angle). Soft parts as in most groups of the family, with geniculate foot.

SUBFAMILY HEMIDONACINAE

Shell inequilateral, much as in Fraginae, but anterior end relatively longer; ribs smooth-surfaced, lacking any intritacalx, intercostal spaces without concentric striations; lateral teeth of hinge elongate. Animal with bilaterally compressed, not geniculate, foot; no pallial eyes or pedal-byssal groove; axis of ctenidia not dorso-ventrally skewed. With only one genus, *Hemidonax*.

Combined Key to Generic Units of Fraginae and Hemidonacinae

1. Ribs sculptured with tubular spines 2
   Ribs variously sculptured but not with tubular spines 3
2. Umbonal ridge weak; outline elliptical to ovate .....AFROCARDIUM [36]
   Umbonal ridge clearly evident; outline trapezoidal to quadrate ...CTENOCARDIA [35]
3. With a deep lunule distorting the hinge .....
   LUNULICARDIA [33]
   With no lunule; hinge not markedly distorted 4
4. Shell compressed laterally; posterior slope nearly flat; height more than twice length
   CORCULUM [34]
   Not laterally compressed; height and length approximately equal 5
5. Anterior lateral teeth crowded against cardinals 6
   Cardinal teeth nearly equidistant between laterals 7
6. Ribs with beaded sculpture along crests .....
   TRIGONIOCARDIA [38]
   Ribs smooth or nearly so ..APIOCARDIA [40]
7. Adult shells small, less than 15 mm in height
   MICROFRAGUM [37]
   Adult shells more than 15 mm in height 8
8. Elongate-trigonal, length greater than height; intercostal spaces not striate .....
   HEMIDONAX [41]
   Length not greater than height; interspaces concentrically striate 9
9. Hinge oblique, not parallel to ventral margin
   FRAGUM [32]
   Hinge roughly parallel to ventral margin .....
   AMERICARDIA [39]

SUBFAMILY PROTOCARDIINAE

Shell rounded-quadrate in outline, nearly equilateral; radial ribs present in most; posterior slope usually more strongly ribbed than remainder of shell, ribs often spinose; ribs of central and anterior slopes, when present, fine and numerous; hinge line long, nearly straight to somewhat arched; cardinal teeth, especially anterior cardinals, well developed; anterior laterals strong (rarely wanting).

Key to generic units

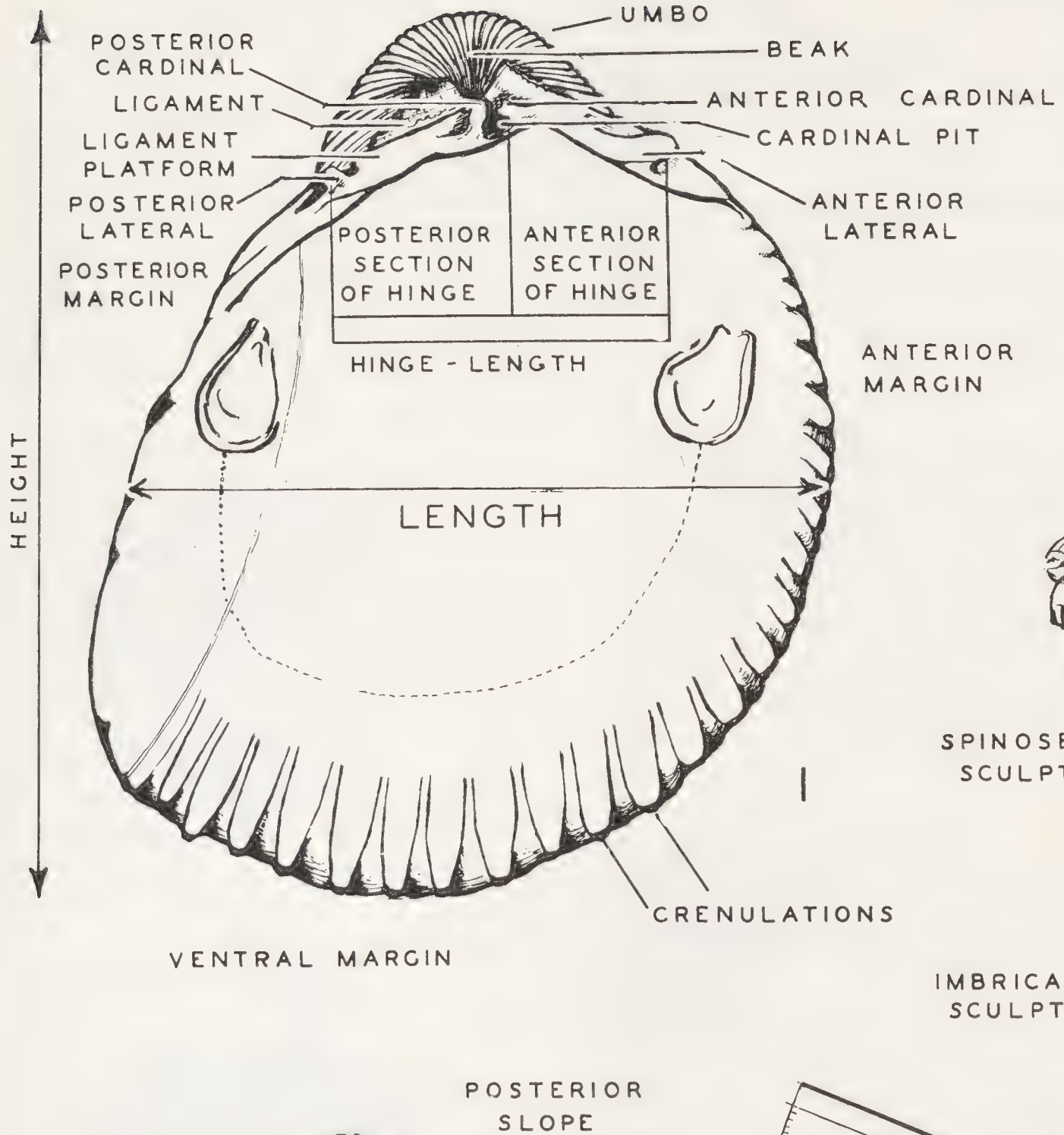
1. Shell smooth, lacking either radial or concentric ribs externally (weak radial threads or internal ridges may occur in some) 2
   Shell with clear-cut external sculpture on at least one slope 6
2. Outline elliptical; shell lacking any umbonal ridge .....INTEGRICARDIUM [50]
   Outline ovate-quadrate; with an umbonal ridge setting off posterior area 3
3. With one or two internal ribs at junction of central slope and posterior area (not always leaving a trace on surface of shell) .....CRYPTOCARDIA [44]
   No internal ribs bounding posterior area (a low ridge is not considered to be a rib) ...4
4. Ligament short, in a deep groove; pallial line entire .....ONESTIA [51]
   Ligament moderate to long; pallial line with a small sinus 5
5. Umbones broad, elevated, nearly central ... TENDAGURIUM [48]
   Umbones narrow, low, anterior to midline .....YOKOYAMAINA [49]
6. Radial ribs present only at umbonal angle LEPTOCARDIA [46]
   Radial ribs not confined to umbonal angle area 7
7. With well-defined, regular concentric ribs on at least the anterior slope 8
   Concentric ribbing weak to wanting or irregular (some oblique sculpture may be present) 12
8. With faint radial ribs on central and anterior slopes, forming cancellate sculpture at intersections .....BREVICARDIUM [43]
   Radial sculpture of anterior and central slopes too weak to cause cancellations ...9
9. Concentric sculpture somewhat irregular, on anterior and ventral marginal areas only .....VARICARDIUM [65]
   Concentric sculpture regular, covering anterior and central slopes 10
10. Height nearly twice length (*i.e.*, shell ovate) PACHYCARDIUM [47]
    Height equal to length (*i.e.*, shell circular or quadrate) 11
11. With a weak internal ridge setting off posterior slope, crenulating margin as one or two large knobs ..GLOBOCARDIUM [45]
    With no internal ridge and no large knob on ventral margin at junction of central and posterior areas .....PROTOCARDIA [42]
12. With secondary sculpture oblique to growth lines on one or more slopes 13
    Secondary sculpture, when present, congruent with growth lines 15
13. Secondary sculpture on anterior and posterior slopes .....DIVARICARDIUM [56]
    Secondary sculpture on central and anterior slopes 14
14. Shell inequilateral, outline oblique; secondary sculpture unevenly spaced and sinuous .....DISCORS [55]
    Shell equilateral, quadrate; secondary sculpture even spaced ...LYROCARDIUM [61]
15. Anterior lateral teeth wanting ..... LOPHOCARDIUM [60]
    Anterior lateral teeth present 16
16. Posterior margin meeting dorsal at a right angle .....JURASSICARDIUM [52]
    Posterior margin meeting dorsal in a wide arc 17
17. Marginal crenulations coarser on posterior margin than elsewhere 18
    Marginal crenulations about the same throughout 22
18. Radial ribs on central and anterior slopes fine to smooth-surfaced 19
    Radial ribs on central or anterior slopes beaded 20
19. Ribs of posterior slope with beads or spines NEMOCARDIUM [53]
    Ribs of posterior slope smooth-surfaced .... HABECARDIUM [58]
20. With beading on anterior slope only ..... TRIFARICARDIUM [64]

PLATE 1

Illustrated terminology

Figures

1. Terms applied to shell interior
2-5. Types of sculpture
6. Terms applied to shell exterior
7. Method of measuring hinge angle



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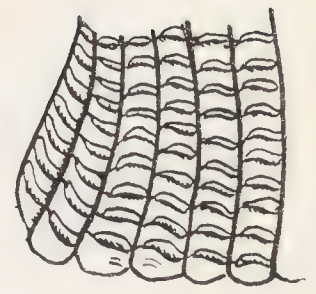
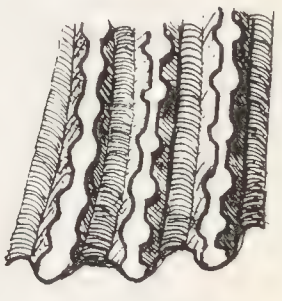


2

THREADED SCULPTURE



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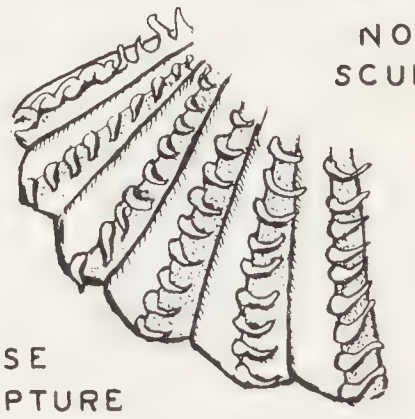
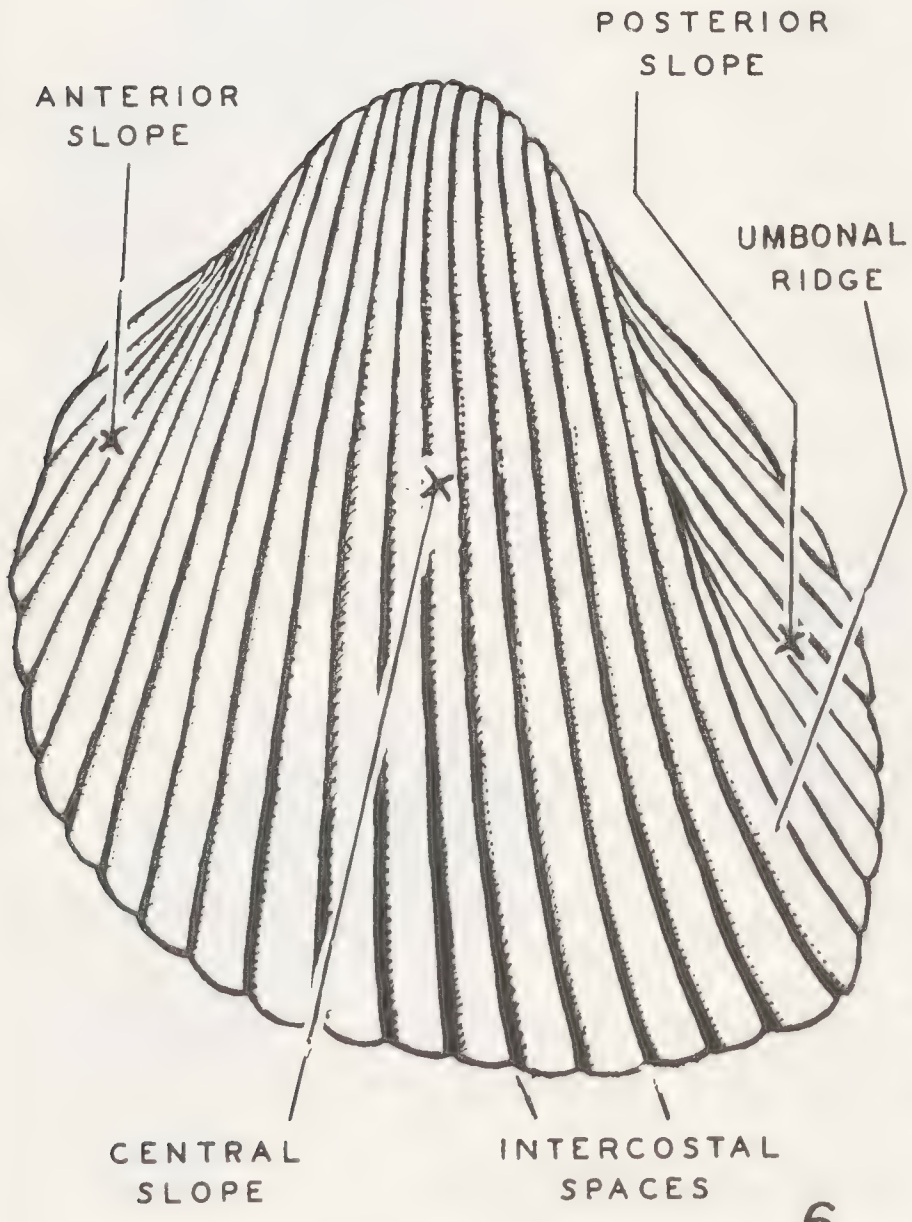


4

SPINOSE SCULPTURE

IMBRICATE SCULPTURE

5



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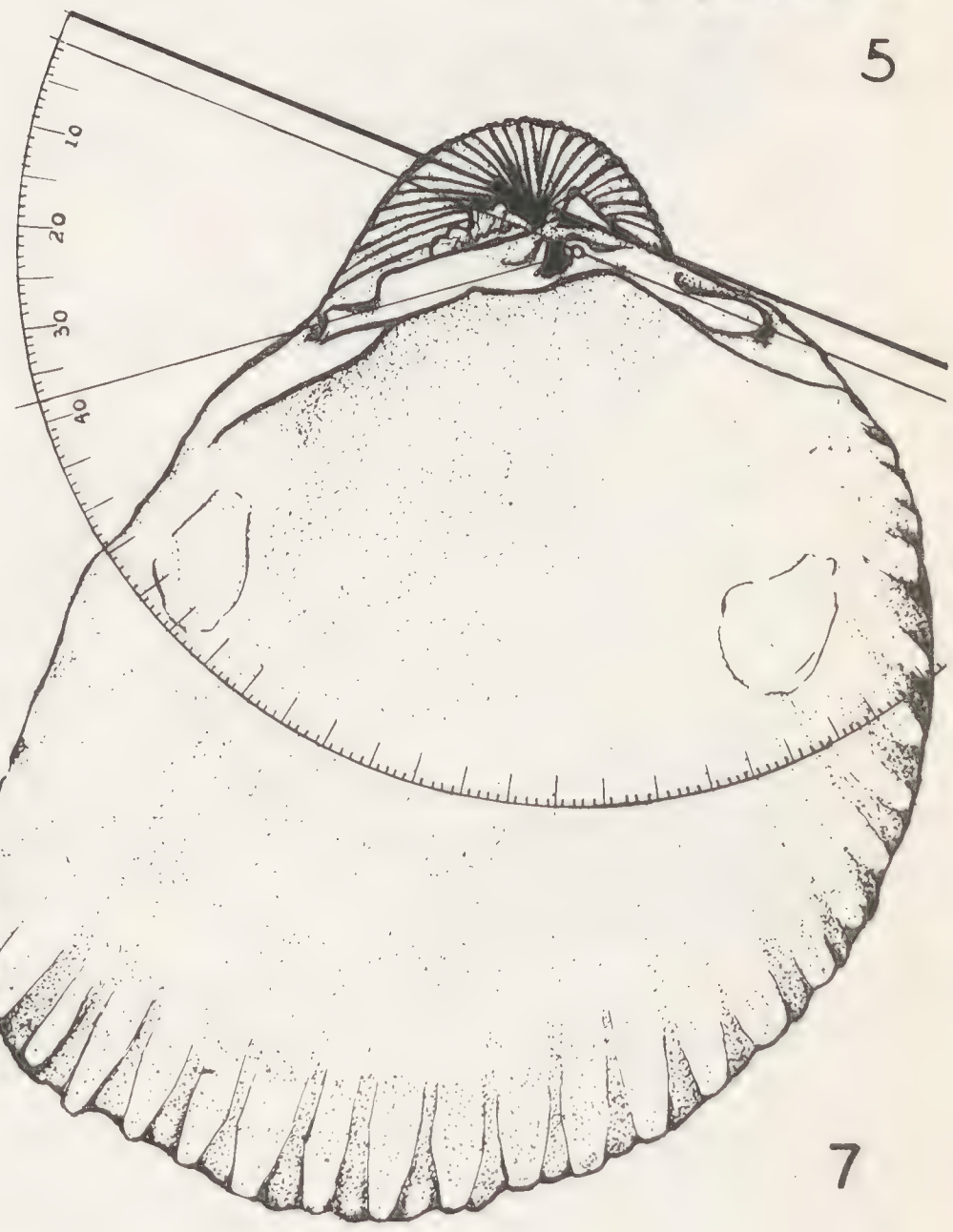

7

PLATE 1

Beading not confined to anterior slope ...21
21. Beaded ribs fine, all the same size .....
MICROCARDIUM [62]
Beading somewhat coarse, alternate ribs larger .....FRIGIDOCARDIUM [57]
22. With secondary concentric laminae throughout .....PRATULUM
Secondary concentric laminae on posterior slope only 23
23. Outline quadrate, hinge relatively long .....
KEENAEA [59]
Outline trigonal, hinge relatively short .....
ARCTOPRATULUM [54]

SUBFAMILY LAEVICARDIINAE

Shell outline elliptical-oblique; posterior slope smoother or less heavily ribbed than remainder of shell; posterior margin entire or slightly wavy but not notched at rib-ends (a few crenulations may be present within); ribs mostly weak or lightly incised; hinge line long, arched; anterior lateral tooth long, often bladelike.

Key to generic units

1. Radial ribs present on anterior and posterior slopes but obsolete on the central part ....
SERRIPES [76]
Radial ribs present on at least central slope 2
2. Outer surface of shell mostly smooth or finely striate (radial ribs may be present internally in middle layer of shell, reflected as fine marginal crenulations) 3
Outer surface with well developed ribs on anterior and central slopes, weaker or absent on posterior 4
3. Marginal crenulations, if present, faint; all shells thin and fragile .....FULVIA [68]
Marginal crenulations well developed; some shells thin, others sturdy .....
LAEVICARDIUM [66]
4. Beaks prosogyrate, the initial part or tip lying above anterior cardinal teeth 5
Beaks orthogyrate, tip above midpoint between the two cardinal teeth 9
5. Ribs triangular in section, often with a periostracal fringe along crest .....
CILIATOCARDIUM [72]
Ribs rounded to squarish in section; periostracum, if present, not fringed 6
6. Intercostal spaces, especially on central slope, as broad as ribs 7
Intercostal spaces narrower than ribs 8
7. Ribs smooth, their tops flattened .....
PLANICARDIUM [75]
Ribs granulated, with slightly rounded tops
FUSCOCARDIUM [73]
8. Ribs sculptured with coarse cross-threads
CLINOCARDIUM [71]
Ribs sculptured with fine cross-threads .....
?KEENOCARDIUM [74]
9. Height greater than length .....
DINOCARDIUM [67]
Height equal to or less than length.....10
10. Anterior part of hinge with a heavy inner buttress .....[KOROBKOVIELLA]

PLATE 2

Subfamily Cardiinae, interiors of left valves

Figures

1. *Loxocardium formosum* (Deshayes). *Ex* Deshayes, 1858. Eoc., France (× 2)
2. *Cardium costatum* Linné. SU specimen. Rec., W. Afr. (× 0.5)
3. *Cardium (Bucardium) ringens* Linné. SU specimen. Rec., W. Afr. (× 1.5)
4. *Vepricardium (Vepricardium) pulchricostatum* Iredale. SU specimen. Rec., Moreton Bay, Australia (× 0.75)
5. *Granocardium (Criocardium) dumosum* (Conrad). SU coll., from plaster cast of topotype. Cret., New Jersey (× 1.5)
6. *Granocardium (Granocardium) proboscideum* (J. Sowerby, 1817). Not the type species. After Woods, 1908. Cret., England (× 1)
7. *Parvicardium commutatum* (Bucquoy, Dautzenberg, & Dollfus). SU specimen. Rec., Palermo, Sicily (× 5)
8. *Plagiocardium (Papillicardium) papillosum* (Poli). SU specimen. Rec., France (× 4)
9. *Granocardium (Ethmocardium) whitei* (Dall). SU specimen, topotype. U. Cret., Montana (× 5)
10. *Plagiocardium (Plagiocardium) granulosum* (Lamarck). SU specimen. U. Eocene, La Guepelle, France (× 2)
11. *Acanthocardia (Schedocardia) hatchetigbeensis* (Aldrich). After original figure. Eoc., Mississippi (× 1)
12. *Acanthocardia (A.) aculeata* (Linné). SU specimen. Rec., France (× 1)

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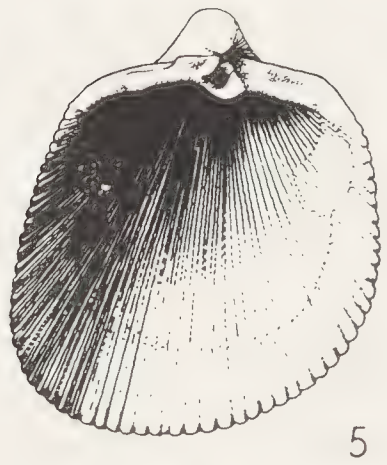
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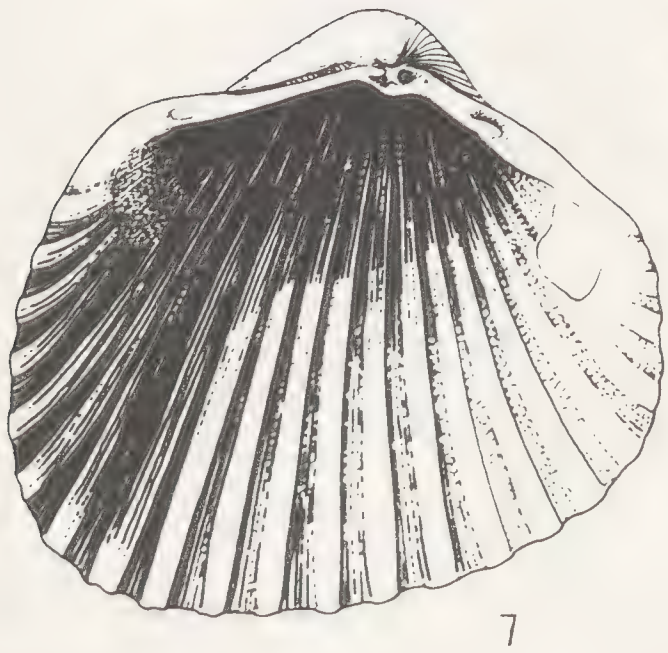
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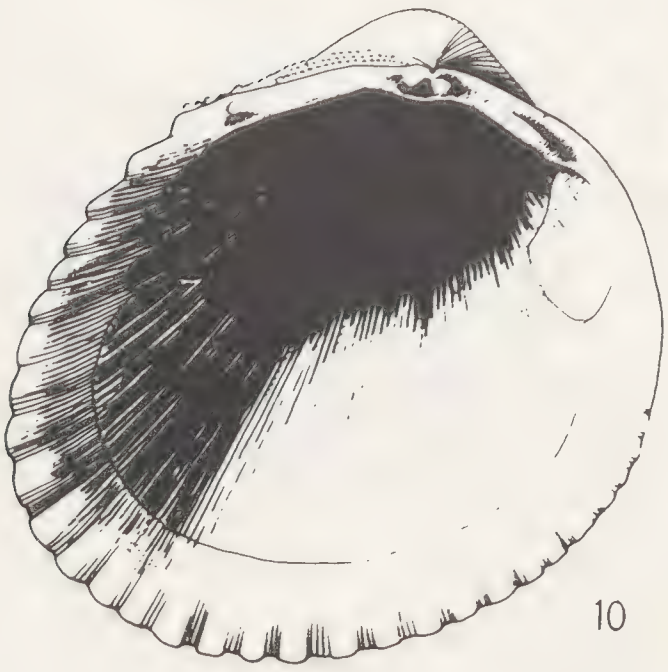
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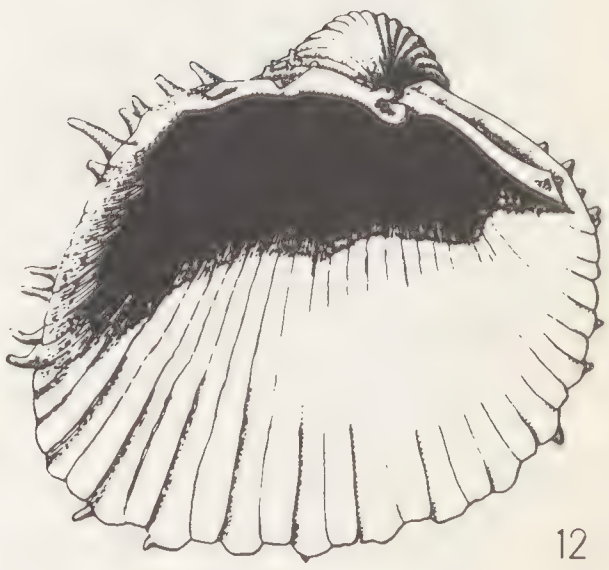

12

PLATE 2

Anterior part of hinge not buttressed 11
11. Posterior margin slightly or moderately gaping .....PROFULVIA [69]
Posterior margin not gaping .....
CERASTODERMA [70]

Section 3. Classification here Adopted

Grouping of recognizably distinct units into larger constellations is a matter of judgment. There are, fortunately, no rules that govern ranking. The patterns arrived at here represent the compromises I would make between the one extreme of a single genus, *Cardium,* with 77 subgenera or "sections" (a term now obsolete under the *International Code of Zoological Nomenclature*) and the other extreme of recognizing as full genera all units that can be distinguished morphologically. The actual ranking may even fluctuate, depending on purpose: a few broad groups would be justified in a semi-popular work, whereas in one addressed to specialists, who need finely-drawn divisions for stratigraphic or ecological interpretations, much more emphasis should be placed on subtle differences. Perhaps one need not always write out in full, for example, *Acanthocardia (Schedocardia)* when referring to *Schedocardia;* but such subordination does serve to point out affinities.

The abbreviations in the column on geographic distribution are explained in a later section of this paper.

Superfamily CARDIACEA Lamarck, 1809
[proposed as a vernacular term, "famille cardiacées"; spelling latinized by Goldfuss, 1820; ranking corrected by Gill, 1871]

Family CARDIIDAE Lamarck, 1809
[vernacular spelling latinized by Broderip, 1839]

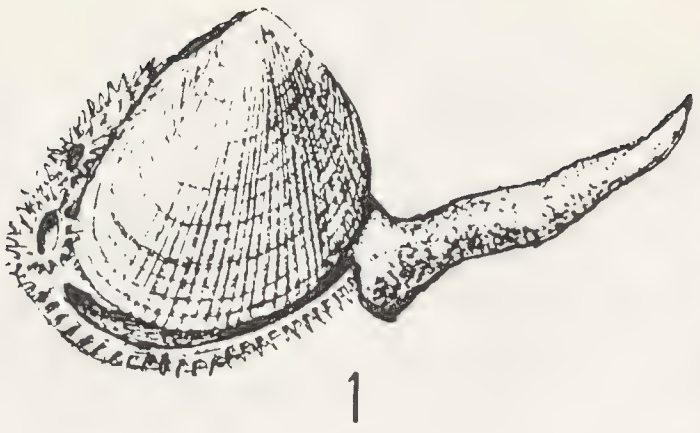
Subfamily CARDIINAE Lamarck, 1809
[first ranked as a subfamily by Stoliczka, 1871]

Taxon	Distribution	Illustrations
1. *Cardium* *(Cardium)*	Mio.-Rec., W. Afr.-Medit.	Pl. 2, fig. 2; Pl. 4, fig. 2
2. *(Bucardium)*	Mio.-Rec., W. Afr.-Medit.	Pl. 2, fig. 3; Pl. 4, fig. 4
3. *(Orthocardium)*	Paleoc.-Eoc., Eu.	Pl. 4, fig. 1
4. *Acanthocardia* *(Acanthocardia)*	U.Oligo.-Rec., Eu.-Medit.-N.Am.	Pl. 2, fig. 12; Pl. 4, fig. 5
5. *(Agnocardia)*	Eoc.-Mio., N.Am.-S.Am.-Eu.	Pl. 3, fig. 9

PLATE 3

Figures

1. Sketch of a living cardiid, showing soft parts. Note genticulate (sickle-shaped) foot projecting anteriorly, at right, long mantle that is slit, below, and short, fringed siphons at left, projecting posteriorly. *Ex* H.&A. Adams, 1858.
2. *Vepricardium (Vepricardium) pulchricostatum* Iredale. *Ex* Moore *et al.,* 1969. Rec., Australia (R ext. × 0.6)
3. *Loxocardium formosum* (Deshayes). *Ex* Deshayes, 1858. Eoc., France (a, detail of sculpture; b, L ext. × 2)
4. *Vepricardium (Perucardia) brueggeni* (Olsson). *Ex* Olsson, 1944. U. Cret., Peru (a, L ext.; b, L, section of the hinge; c, detail of sculpture; a-b, × 0.5)
5. *Incacardium mellisum* (Olsson). *Ex* Olsson, 1944. U. Cret., Peru (a, R ext.; b, R int.; × 1.5)
6. *Septocardia typica* (Hall & Whitfield). *Ex* Moore *et al.,* 1969. a, R int.; b, L int. (Trias., Alaska); c, R ext. (Trias., Peru), holotype of *S. peruviana* (Cox) (?=*S. typica*). (a,b, × 2; c, × 1.5)
7. *Granocardium (Criocardium) dumosum* (Conrad). *Ex* Moore *et al.,* 1969. Cret., New Jersey (a, R ext.; b, R int.; × 1)
8. *Granocardium (G.) carolinum* (Orbigny). *Ex* Orbigny, 1844. Cret., France (L ext. × 1)
9. *Acanthocardia (Agnocardia) sorrentoensis* (M. A. Hanna, 1927). Not type species. Eoc., California (a, enlarged detail of sculpture; b, L ext. × 1.5)



1

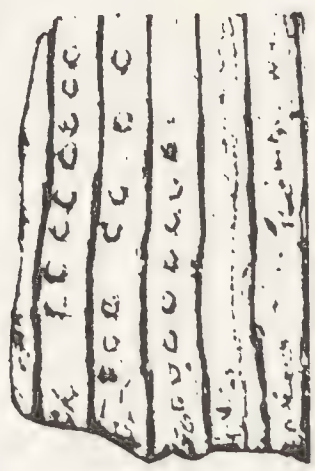
2

3a

3b

4a

4b



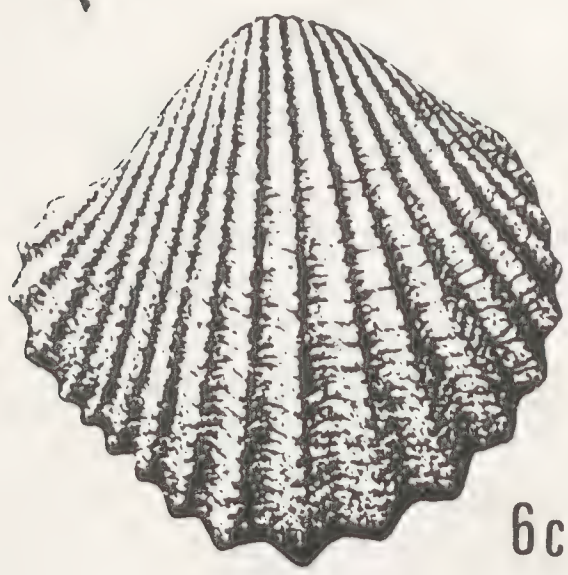
4c

5a

5b

6a

6b



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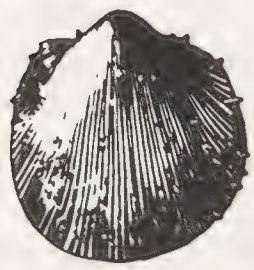
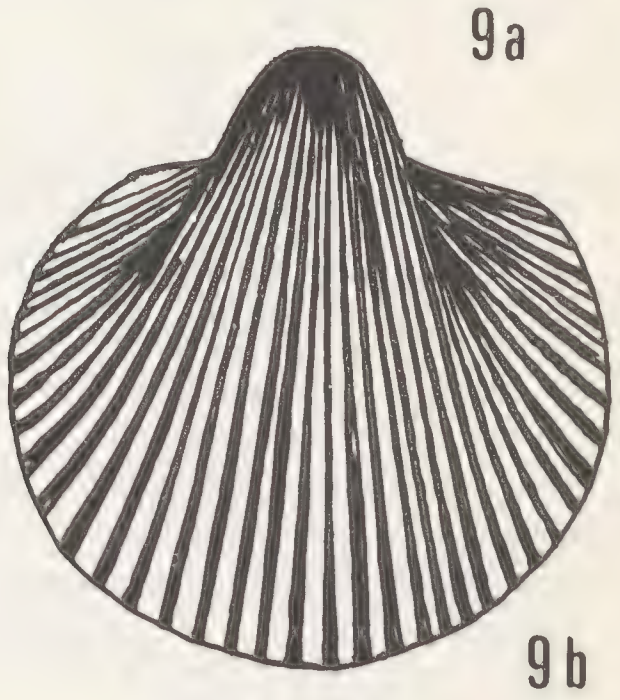


7a

7b

8

9a



9b

PLATE 3

6. *(Europicardium)*	Eoc.-Plio.-?Rec., Eu.	Pl. 4, fig. 7
7. *(Rudicardium)*	Mio.-Rec., Medit.	Pl. 4, fig. 3
8. *(Schedocardia)*	Paleoc.-Eoc., W.Afr.-SE Asia-S.Am.	Pl. 2, fig. 11
9. *Granocardium (Granocardium)*	L.-U.Cret., Eu.-Asia-Afr.-S.Pac.-N.-S.Am.	Pl. 2, fig. 6; Pl. 3, fig. 8
10. *(Criocardium)*	Cret., N.Am.-Eu.-W.Asia	Pl. 2, fig. 5; Pl. 3, fig. 7
11. *(Ethmocardium)*	U.Cret., N.Am.-S.Pac.	Pl.2, fig. 9
12. *Incacardium*	U.Cret., Peru	Pl. 3, fig. 5
13. *Loxocardium*	Eoc.-Mio., Eu.-?N.Am.	Pl. 2, fig. 1; Pl. 3, fig. 3
14. *Parvicardium*	Eoc.-Rec., Eu.-N.Atl.-E.Afr.-?W.N.Am.	Pl. 2, fig. 7
15. *Plagiocardium (Plagiocardium)*	Paleoc.-Mio.,Eu.-E. Ind.	Pl. 2, fig. 10
16. *(Maoricardium)*	Oligo.-Rec., Afr.-N.Z.	Pl. 4, fig. 6
17. *(Papillicardium)*	Eoc.-Rec.,Eu.-W.Asia	Pl. 2, fig. 8
?17a. *Pleuriocardia (Pleuriocardia)*	L.-U.Cret., N.Am.-Eu.	
?17b. *(Dochmocardia)*	U.Cret., N. Am.-Eu.	
18. *Septocardia*	U.Trias., N.Am.-S.Am.-Eu.	Pl. 3, fig. 6
19. *Vepricardium (Vepricardium)*	Paleoc.-Rec., Eu.-Afr.-Austral.	Pl. 2, fig. 4; Pl. 3, fig. 2
20. *(Hedecardium)*	Eoc.-Mio.,S.Pac.-S.Asia	Pl. 4, fig. 8
21. *(Perucardia)*	U.Cret., Peru	Pl. 3, fig. 4

Subfamily TRACHYCARDIINAE Stewart, 1930

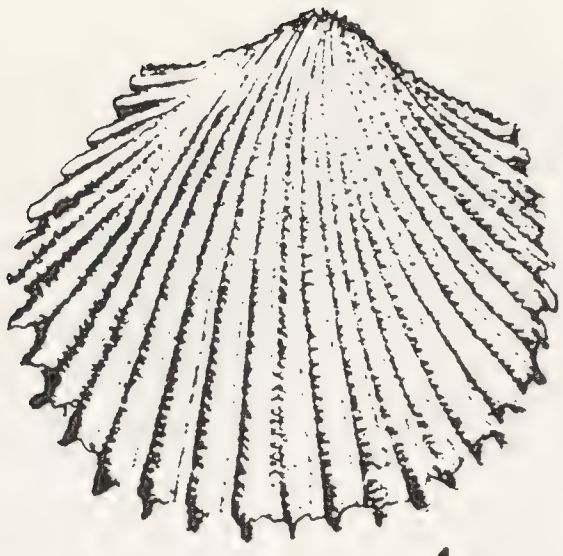
22. *Trachycardium (Trachycardium)*	Oligo.-Rec., N.Am.-S.Am.	Pl. 5, fig. 1; Pl. 8, fig. 5
23. *(Conilocardium)*	Mio., S.E. N.Am.	Pl. 6, fig. 7; Pl. 8, fig. 4
24. *(Dallocardia)*	Oligo.-Rec., N.Am.-S.Am.	Pl. 5, fig. 4; Pl. 8, fig. 3
25. *(Mexicardia)*	Mio.-Rec., W.C.Am.-S.Am.	Pl. 5, fig. 5; Pl. 8, fig. 2
26. *(Phlogocardia)*	Mio.-Rec., C. Am.	Pl. 5, fig. 3; Pl. 8, fig. 1
27. *Acrosterigma (Acrosterigma)*	Mio.-Plio., S.E. USA-W.Ind.	Pl. 5, fig. 6; Pl. 6, fig. 8
28. *(Ovicardium)*	Plio., S. Pac.	Pl. 6, fig. 12
29. *(Regozara)*	Neog.-Rec., E.Ind.-Austral.	Pl. 8, fig. 8
30. *Papyridea*	Mio.-Rec., tropical Am.	Pl. 5, fig. 7; Pl. 6, fig. 11
31. *Vasticardium*	U. Oligo.-Rec., IndoPac.-C.Am.-Eu.	Pl. 5, fig. 2

PLATE 4

Cenozoic Cardiinae

Figures

1. *Cardium (Orthocardium) porulosum* (Solander). *Ex* Deshayes, 1824-37. Eoc., France (a, R ext.; b, L hinge; c, R hinge; × 1)
2. *Cardium (Cardium) costatum* Linné. *Ex* Chenu, 1862. Rec., W. Afr. (R ext. × 0.5)
3. *Acanthocardia (Rudicardium) tuberculata* (Linné). *Ex* Chenu, 1862. Rec., Medit. (L ext. × 1)
4. *Cardium (Bucardium) ringens* Linné. Moore *et al.*, 1969, *ex* Chenu, 1862. Rec., W. Afr. (× 0.5)
5. *Acanthocardia (A.) aculeata* (Linné). *Ex* Chenu, 1862. Rec., Medit. (L ext. × 1)
6. *Plagiocardium (Maoricardium) spatiosum* (Hutton). *Ex* Marwick, 1944. Plio., N. Z. (L int. × 0.7)
7. *Acanthocardia (Europicardium) multicostata* (Brocchi). *Ex* Brocchi, 1814. Neog., Italy (L int.; R ext.; × 1)
8. *Vepricardium (Hedecardium) waitakiense* (Suter). *Ex* Marwick, 1944. Oligo., N. Z. (a, R int.; b, L int.; c, L ext.; × 0.8)



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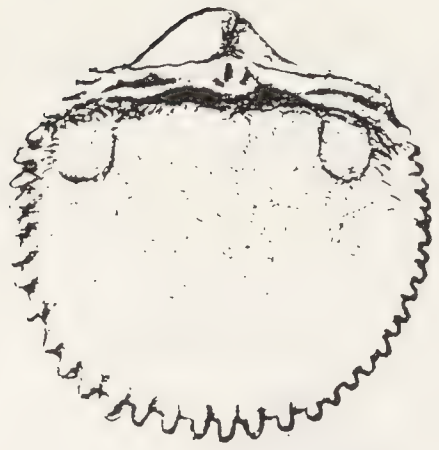

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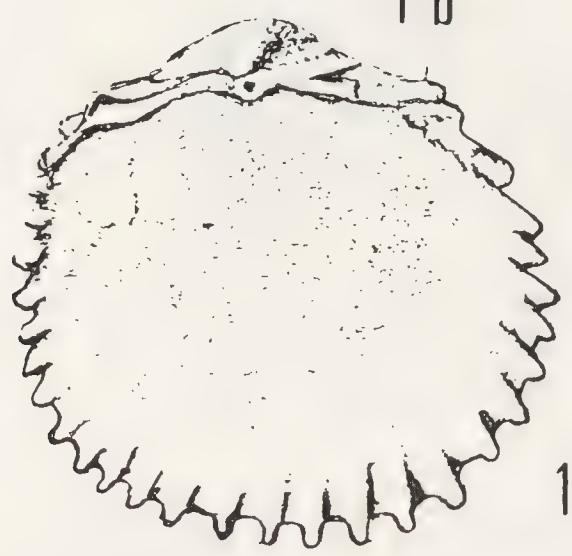

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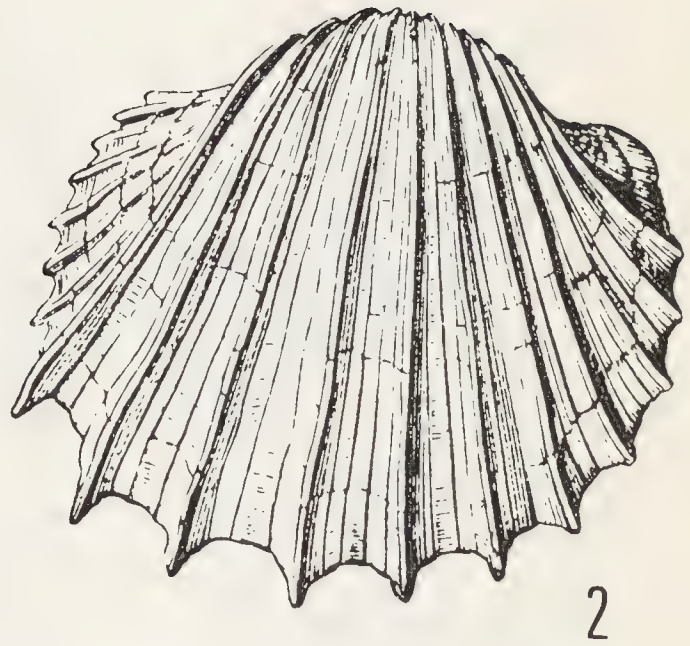

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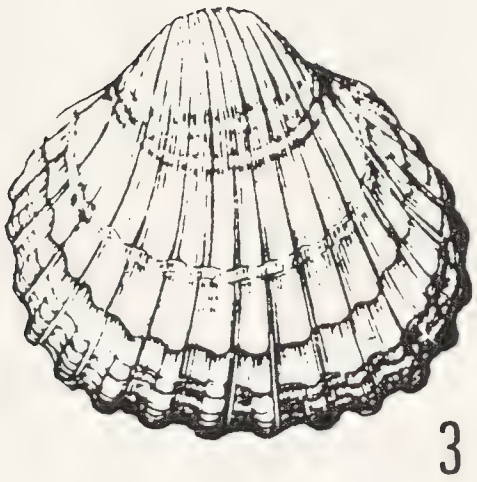

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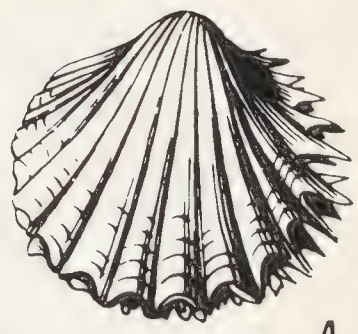

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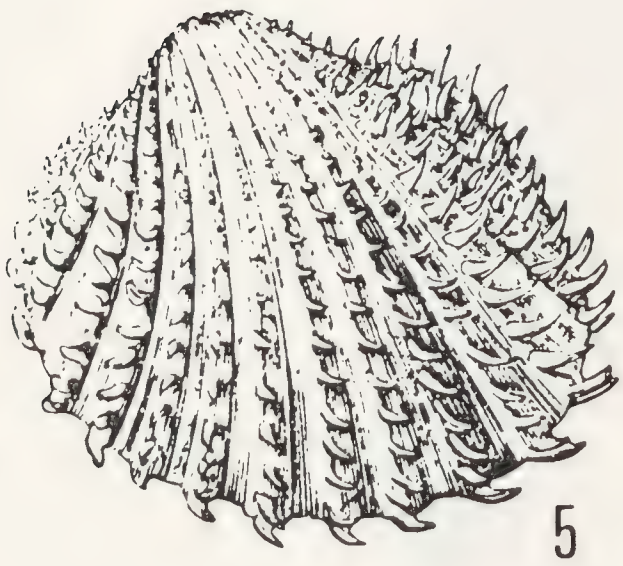

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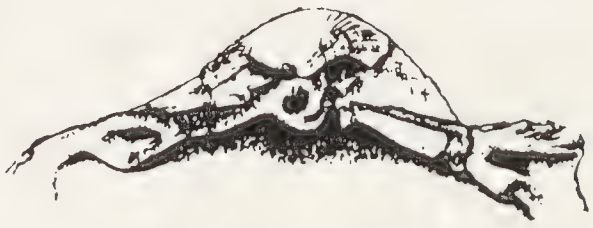
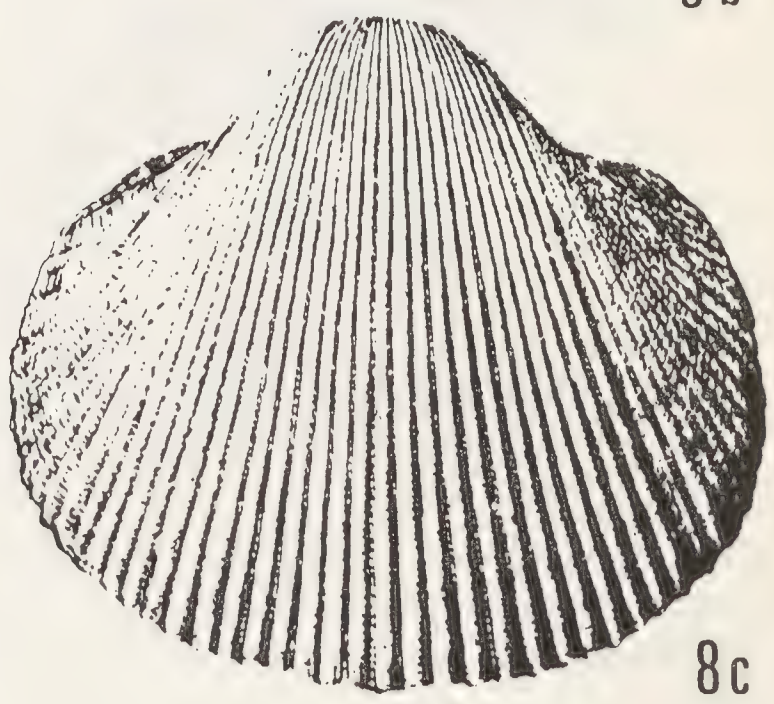


8a

8b

7



8c

PLATE 4

Subfamily FRAGINAE Stewart, 1930

32.	*Fragum* *(Fragum)*	Mio.-Rec., E.Ind.-Austral.-W.Afr.-SE USA	Pl. 6, fig. 5; Pl. 7, fig. 5
33.	*(Lunulicardia)*	Pleist.-Rec., IndoPac.-Japan	Pl. 6, fig. 3; Pl. 7, fig. 6
34.	*Corculum*	Rec., E.Indies	Pl. 6, fig. 6; Pl. 7, fig. 2
35.	*Ctenocardia* *(Ctenocardia)*	Mio.-Rec., E.Afr.-E.Ind.	Pl. 6, fig. 4; Pl. 7, fig. 1
36.	*(Afrocardium)*	Pleist.-Rec.,S.Afr.-E.Ind.-Austral.	Pl. 7, fig. 3
37.	*(Microfragum)*	Rec., E.Ind.-Japan	Pl. 6, fig. 2
38.	*Trigoniocardia* *(Trigoniocardia)*	Oligo.-Rec., tropical Am.-W.Afr.	Pl. 6, fig. 10; Pl. 7, fig. 4
39.	*(Americardia)*	L.Mio.-Rec., N.Am.-S.Am.	Pl. 7, fig. 7
40.	*(Apiocardia)*	Plio.-Rec., tropical Am.	Pl. 6, fig. 9

Subfamily HEMIDONACINAE Iredale and McMichael, 1962
(as Hemidonacidae; rank reduced, Boss, 1971)

41.	*Hemidonax*	Rec., E.Indies	Pl. 6, fig. 1

Subfamily PROTOCARDIINAE Keen, 1951

42.	*Protocardia* *(Protocardia)*	U.Trias.-U.Cret.,cosmop.	Pl. 9, fig. 11; Pl. 10, fig. 2
43.	*(Brevicardium)*	U.Cret., N.Am.-Asia-Eu.	Pl. 10, fig. 3
44.	*(Cryptocardia)*	M.-U.Jur., Eu.	Pl. 10, fig. 4
45.	*(Globocardium)*	L.Cret., Eu.-E.Afr.-Japan	Pl. 10, figs. 7, 8
46.	*(Leptocardia)*	L.-U.Cret., N.Am.	Pl. 9, fig. 7
47.	*(Pachycardium)*	L.-U.Cret.,Eu.-Asia,N.-S.Am.	Pl. 9, fig. 5
48.	*(Tendagurium)*	Jur.-Cret., Afr.-Eu.-E.Asia	Pl. 9, fig. 8
49.	*(Yokoyamaina)*	Jur., E.Asia	Pl. 10, fig. 6
50.	*Integricardium* *(Integricardium)*	M.Jur.-U.Cret.,Eu., Asia, Afr.	Pl. 9, fig. 10; Pl. 10, fig. 5
51.	*(Onestia)*	L.-U.Cret., Canada	Pl. 9, fig. 9
52.	*Jurassicardium*	Jur., Eu.(France), ?S.Am.	Pl. 9, fig. 12; Pl. 10, fig. 1
53.	*Nemocardium* *(Nemocardium)*	L.Cret.-Rec., cosmop.	Pl. 9, fig. 3; Pl. 11, fig. 6
54.	*(Arctopratulum)*	Oligo.-Mio.,Japan-W.N.Am.	Pl. 8, fig. 7; Pl. 11, fig. 5
55.	*(Discors)*	Eoc.-Mio., Eu.-Asia	Pl. 9, fig. 13
56.	*(Divaricardium)*	Oligo.-Plio., Eu.-Asia	Pl. 11, fig. 4
57.	*(Frigidocardium)*	Mio.-Rec.,Japan-IndoPac	Pl. 11, fig. 2
58.	*(Habecardium)*	Eo.-Oligo., Eu.	Pl. 11, fig. 10

PLATE 5

Interior views, left valves, subfamily Trachycardiinae

Figures

1. *Trachycardium (Trachycardium) isocardia* (Linné). SU specimen. Rec., Florida (× 1)
2. *Vasticardium elongatum* (Bruguière). SU specimen. Rec., Luzon I., Philippines (× 0.5)
3. *Trachycardium (Phlogocardia) belcheri* (Broderip & Sowerby). SU specimen. Rec., Gulf of California (× 1.5)
4. *Trachycardium (Dallocardia) quadragenarium* (Conrad). SU specimen. Rec., San Pedro, California (× 0.25)
5. *Trachycardium (Mexicardia) procerum* (Sowerby). SU specimen. Rec., Nicaragua (× 0.7)
6. *Acrosterigma (Acrosterigma) dalli* (Heilprin). SU specimen. Caloosahatchee Pliocene, Florida (× 0.5)
7. *Papyridea soleniformis* (Bruguière). SU specimen. Rec., John's Pass, Florida (× 1.4)

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2

3

4

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6

7

PLATE 5

59.	*(Keenaea)*	Oligo.-Rec.,Japan,W.N.Am.	Pl. 11, fig. 1
60.	*(Lophocardium)*	Mio.-Rec., C.Am.-S.Am.	Pl. 9, fig. 1
61.	*(Lyrocardium)*	Mio.-Rec., IndoPac.	Pl. 9, fig. 6; Pl. 11, fig. 7
62.	*(Microcardium)*	Mio.-Rec., C.Am.	Pl. 9, fig. 4
63.	*(Pratulum)*	L.Cret.-Rec.,Eu.-S.Pac.	Pl. 9, fig. 2; Pl. 11, fig. 9
64.	*(Trifaricardium)*	Pleist.-Rec., Japan	Pl. 11, fig. 3
65.	*(Varicardium)*	Mio., N.Z.	Pl. 11, fig. 8
?65a.	*Pleuriocardia*		
	(Pleuriocardia)	L.-U.Cret., N.Am.-Eu.	
?65b.	*(Dochmocardia)*	U.Cret., N. Am.-Eu.	

Subfamily LAEVICARDIINAE Keen, 1936

66.	*Laevicardium*		
	(Laevicardium)	Eoc.-Rec.,E.-W.Atl., IndoPac-E.Pac.	Pl. 12, fig. 4; Pl. 13, fig. 2
67.	*(Dinocardium)*	Eo.-Rec., N.Am.-S.Am.	Pl. 12, fig. 6
68.	*(Fulvia)*	Pleist.-Rec.,IndoPac-Japan	Pl. 12, fig. 1
69.	*(Profulvia)*	Oligo.-Plio., NW Pac.-Alaska	Pl. 13, fig. 6
70.	*Cerastoderma*		
	(Cerastoderma)	U.Oligo.-Rec., Eu.-N.Atl.	Pl. 12, fig. 2; Pl. 13, fig. 1
	[*(Korobkoviella)*	U.Oligo., USSR; transferred to Lymnocardiidae, subfamily Lymnocardiinae by Kafanov & Popov, 1977]	
71.	*Clinocardium*		
	(Clinocardium)	M.Oligo.-Rec., N.Pac.	Pl. 8, fig. 6; Pl. 12, fig. 3; Pl. 13, fig. 5
72.	*(Ciliatocardium)*	L.Oligo.-Rec., NW Pac.-N.Atl.	Pl. 13, fig. 7
73.	*(Fuscocardium)*	Pleist., Japan	Pl. 13, fig. 8
74.	?*(Keenocardium)*	M.Oligo.-Rec., N.Pac.	Pl. 8, fig. 9
75.	*(Planicardium)*	Mio., N.W.Atl.	Pl. 13, fig. 4
76.	*Serripes*	Mio.-Rec., N.Atl.-N.Pac.-Japan	Pl. 12, fig. 5; Pl. 13, fig. 3

PLATE 6

Subfamilies Trachycardiinae, Fraginae and Hemidonacinae, mainly exterior views
Figures

1. *Hemidonax donaciformis* (Bruguière). Rec., E. Ind. (a, L ext.; b, R int., *ex* Tryon, 1870; c, L ext., *ex* Chenu, 1862; × 1)
2. *Ctenocardia (Microfragum) festiva* (Deshayes). *Ex* Prashad, 1932. (L ext. × 1)
3. *Fragum (Lunulicardia) retusum* (Linné). *Ex* Chenu, 1862. Rec., E. Ind. (a, R ext.; b, anterior view, both valves. a, × 0.5; b, × 1)
4. *Ctenocardia (Ctenocardia) symbolica* (Iredale). *Ex* Chenu, 1862. Rec., E. Ind. (a, posterior view, both valves; b, R ext.; × 1)
5. *Fragum (Fragum) fragum* (Linné). *Ex* Moore *et al.*, 1969. Rec., E. Ind. (R ext. × 1)
6. *Corculum cardissa* (Linné). *Ex* Chenu, 1862. Rec., E. Ind. (Anterior view, both valves × 1)
7. Diagrammatic section of *Trachycardium (Conilocardium) cestum* (Dall), to show profile of radial ribbing. *Ex* Vokes, 1977. Mio., Florida (× 2)
8. *Acrosterigma (A.) dalli* (Heilprin). *Ex* Moore *et al.*, 1969. Plio., Florida (L ext. × 0.25)
9. *Trigoniocardia (Apiocardia) obovalis* (Sowerby). *Ex* Olsson, 1961. Rec., N. Peru (L ext. × 2)
10. *Trigoniocardia (T.) granifera* (Broderip & Sowerby). *Ex* Olsson, 1961. Rec., Ecuador (L ext. × 2)
11. *Papyridea soleniformis* (Bruguière). *Ex* Moore *et al.*, 1969. Rec., Florida (a, R int.; b, L ext.; × 1)
12. *Acrosterigma (Ovicardium) rossi* (Marwick). *Ex* Marwick, 1944. Plio., N. Z. (a, L ext.; b, L int.; × 0.6)

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1b

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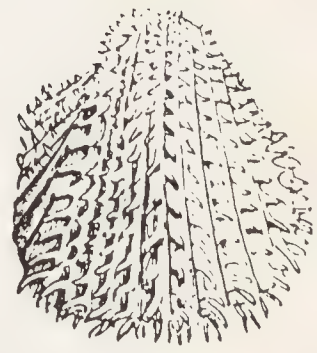
3b

4a



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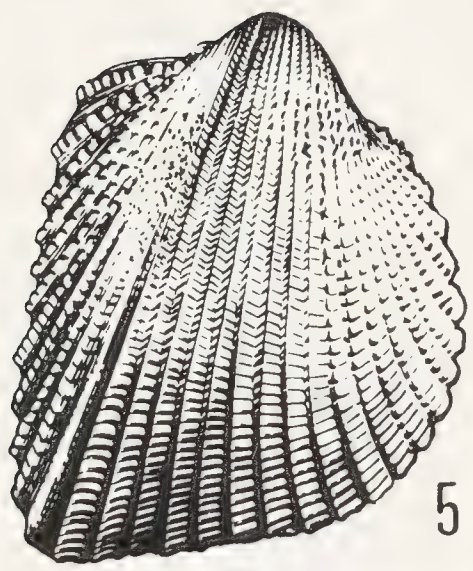

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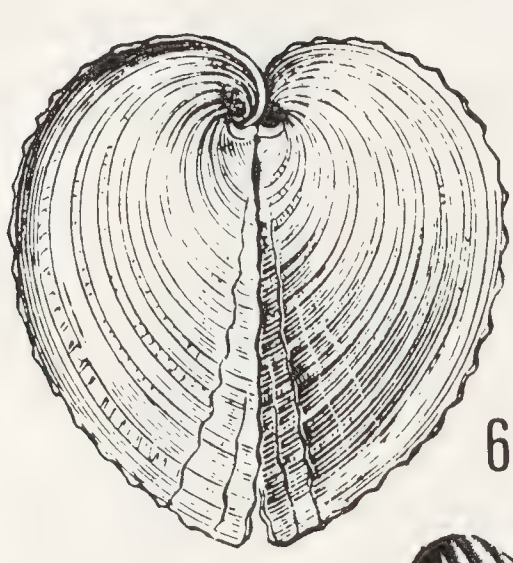

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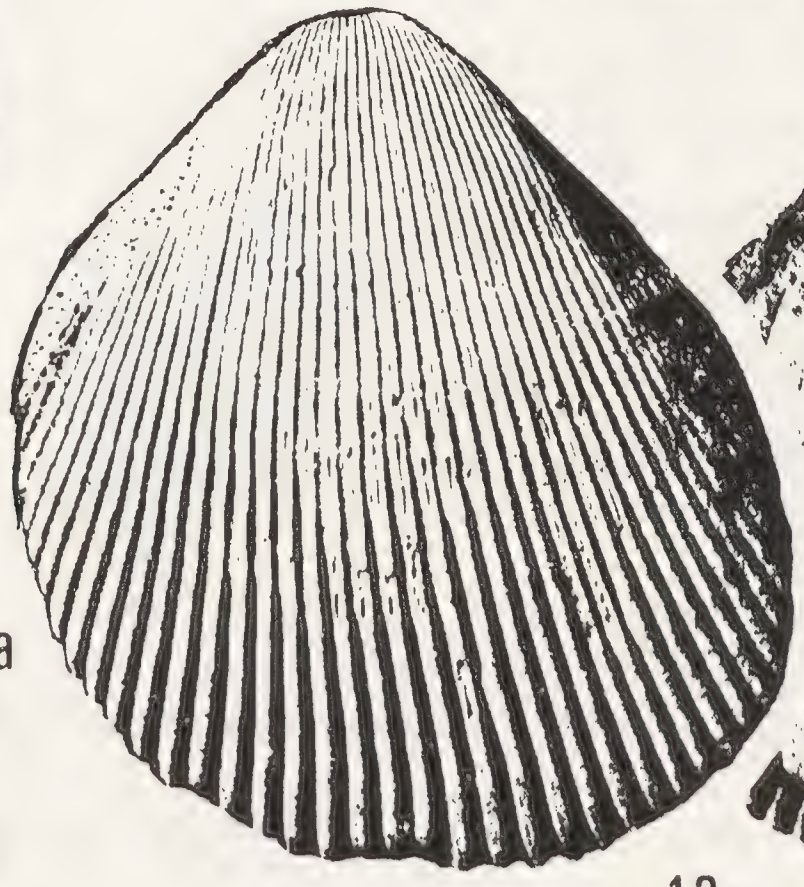

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PLATE 6

Section 4: Phylogeny

One could hope that arranging the genera in the order of when they appeared in time would sketch the outline of a phylogeny. The matter, however, is complicated by several factors, not the least of which is gaps in the fossil record, whether from loss by weathering and erosion, from chemical or physical alteration of sediments (diagenesis), or from lack of sufficient exploration and study. A particularly good illustration is the line of *Cardium* s. s. The earliest record of any cardiid seems to be *Septocardia*, in the Norian Stage of the Upper Triassic. Well preserved specimens of this taxon have been found both in North America and in South America. Records of any plausible descendants in the Jurassic and Lower Cretaceous are lacking, but in the Upper Cretaceous of Peru there is a good candidate in *Incacardium* as a successor. Then, in the Lower Tertiary of Europe, there is *Orthocardium* that may fit into this line, although its affinities seem closer to the later Tertiary *Cardium-Bucardium* descendants than to the presumed ancestral forms. Beyond the general cardiid pattern of radial ribbing, deployment of cardinal and lateral teeth, and features of internal scars, this entire stock does not seem closely related to other cardiids. A second line of Cardiinae also originated in the Mesozoic: *Granocardium*, which was widespread in Lower and Upper Cretaceous time, giving off some other Cretaceous offshoots, no one of which spans the critical time-boundary between Cretaceous and Paleocene. However, the line allied to *Acanthocardia* is a plausible descendant.

Tables 2 to 6* show the geologic distribution of the cardiid taxa by subfamilies. I make no attempt here to draw connecting lines between generic units. These charts simply report presence or absence (shown by a long dash) of each unit at each geologic period, insofar as my records go. To draw phylogenetic lines, one would need to be able to reconcile geographic distribution with past opportunities for interchange of faunas between continents, a task we are only now beginning to approach through the new concepts of plate tectonics, sea-floor spreading, and continental drift. Rather, this analysis records my judgments as I examined the literature during the years of survey. Some of the apparent gaps might be filled in if a canvass were made of locality lists, for by concentrating on illustrated material, I may well have overlooked reported occurrences, especially in the Pleistocene. But even with uncertainties in detail, the picture of the family as a whole is satisfyingly consistent.

Somewhere within the later Paleozoic and early Mesozoic Heterodonta must lie buried the roots of the Cardiidae and related families of the superfamily Cardiacea. Searching among the figures of heterodonts in the *Treatise on Invertebrate Paleontology*, one finds several plausible ancestral stocks in the Carditacea and the Crassatellacea. For example, Protocardiinae resemble in many ways the Myophoricardiidae in Cras-

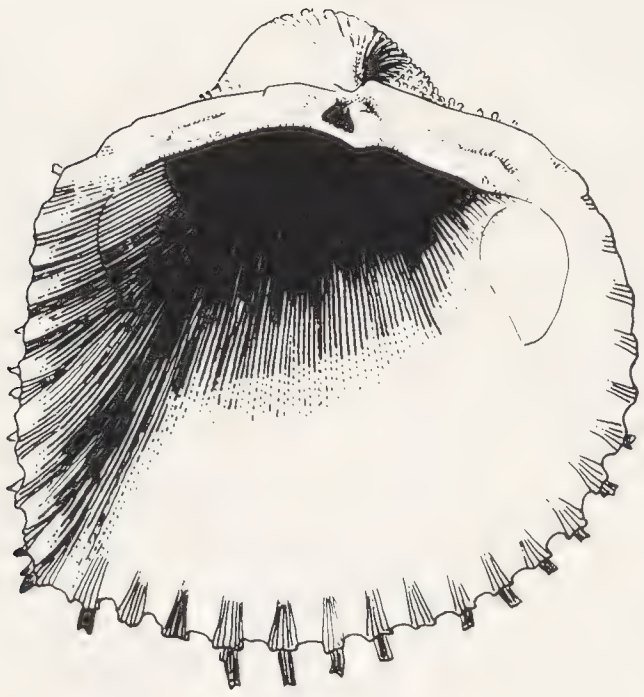
*In tables 2 to 6, generic names are abbreviated in order to compress the tables to one-page size. Full names are readily available in Sections 1 and 3.

PLATE 7

Subfamily Fraginae, interior of left valves
All from specimens in the SU collection

Figures

1. *Ctenocardia (Ctenocardia)* cf. *C. symbolica* (Iredale). Rec., Andaman Is. (× 3)
2. *Corculum cardissa* (Linné). Rec., Philippine Is. (× 1)
3. *Ctenocardia (Afrocardium) exocha* (Melvill & Standen, 1906). Not type species. Rec., Persian Gulf (× 5)
4. *Trigoniocardia (Trigoniocardia) granifera* (Broderip & Sowerby). Rec., Gulf of California (× 4)
5. *Fragum (Fragum) fragum* (Linné). Rec., Fiji Is. (× 1.4)
6. *Fragum (Lunulicardia) retusum* (Linné). Rec., Hong Kong (× 1)
7. *Trigoniocardia (Americardia) media* (Linné). Rec., Florida (× 1.5)



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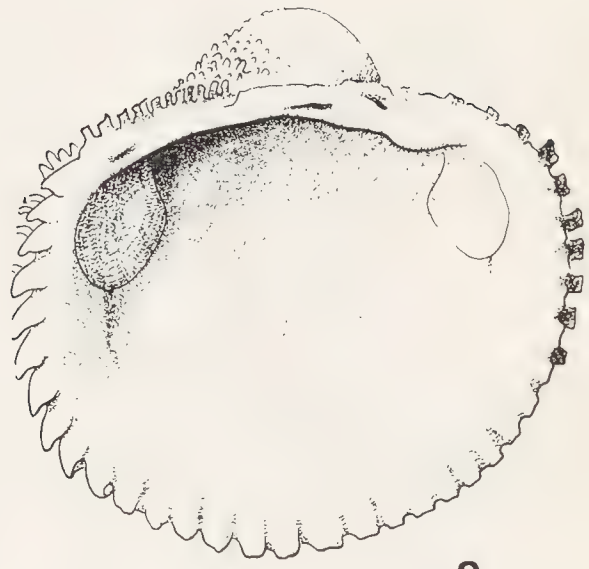

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PLATE 7

Table 2. Geologic history of the Cardiinae

Recent	Card.	Buc.	Vepr.		Papi.		Maor.	Parv.			Acant.	Rudi.	?Euro.
Pleistocene	Card.	—	—		Papi.		—	Parv.			Acant.		—
Pliocene	Card.	—	Vepr.		Papi.		Maor.	Parv.			Acant.		Euro.
Miocene	Card.	Buc.	Vepr.	Hede.	Papi.	Plag.	Maor.	Parv.	Loxo.	Agno.	Acant.		Euro.
Oligocene	Orth.		Vepr.	Hede.	Papi.	Plag.	Maor.	Parv.	Loxo.	Agno.	Acant.		Euro.
Eocene	Orth.		Vepr.	Hede.	Papi.	Plag.		Parv.	Loxo.	Agno.	Sched.		Euro.
Paleocene	Orth.		?Vepr.			Plag.			Loxo.		?Sched.		
Upper Cretaceous	Inca.		Peru.		Crio.	Grano.		?Pleu.	?Doch.		Ethmo.		
Lower Cretaceous	—				Crio.	Grano.		?Pleu.					
Upper Jurassic	—												
Middle Jurassic	—												
Lower Jurassic	—												
Upper Triassic	Septo.												

Table 3. Geologic history of the Trachycardiinae

Recent	Trach.	Dallo.	Mexi.		Phlog.			Vasti.	Reg.	Papy.
Pleistocene	Trach.	Dallo.	Mexi.		—			Vasti.	—	Papy.
Pliocene	Trach.	Dallo.	—		—	Acro.	Ovi.	—	Reg.	Papy.
Miocene	Trach.	Dallo.	Mexi.	Conil.	Phlog.	Acro.		Vasti.		Papy.
Oligocene	Trach.	Dallo.						Vasti.		
Eocene										
Paleocene										

Table 4. Geologic history of the Fraginae

Recent	Lunul.	Frag.	Corc.	Afro.	Cteno.	Micro.	Ameri.	Trigo.	Apio.
Pleistocene		Frag.		Afro.	Cteno.		Ameri	Trigo.	Apio.
Pliocene		Frag.			Cteno.		Ameri.	Trigo.	Apio.
Miocene		Frag.			Cteno.		Ameri.	Trigo.	
Oligocene								Trigo.	
Eocene								Trigo.	
Paleocene									

Table 5. Geologic history of the Protocardiinae

Recent		Mic.	Lyro.	Loph.				Nemo.		Prat.		Keen.	Frig.	Trif.	
Pleist.		—	Lyro.	—				Nemo.		—		Keen.	—	Trif.	
Pliocene		—	Lyro.	—	Div.			Nemo.		Prat.		—	Frig.		
Miocene		Mic.	Lyro.	Loph.	Div.	Disc.	Var.	Nemo.		Prat.	Arct.	—	Frig.		
Oligocene					Div.	Disc.		Nemo.	Habe.	Prat.	Arct.	Keen.			
Eocene						Disc.		Nemo.	Habe.	Prat.					
Paleocene								Nemo.	?Hab.	Prat.					
Upper Cret.	Ones.	Int.		?Ten.			Lep.	Pach.	Brev.	Prot.	Nemo.		Prat.	?Pleu.	?Doch.
Low. Cret.	Ones.	Int.		Tend.	Cryp.	Glob.	Lep.	Pach.		Prot.	Nemo.		Prat.	?Pleu.	
Upper Jur.		Int.		Tend.	Cryp.					Prot.					
Mid. Jura.		Int.	Yok.	Tend.			Jur.			Prot.					
Low. Jura.										Prot.					
U. Triassic										Prot.					

Table 6. Geologic history of the Laevicardiinae

Recent	Laevi.	Dino.	Ful.		Ceras.	Clino.			Ciliat.	Serr.
Pleistocene	Laevi.	—	Ful.		Ceras.	Clino.	Fusco.		Ciliat.	Serr.
Pliocene	Laevi.	—		Prof.	Ceras.	Clino.			Ciliat.	Serr.
Miocene	Laevi.	Dino.		Prof.	Ceras.	Clino.		Plani.	Ciliat.	Serr.
Oligocene	Laevi.	Dino.		Prof.	Ceras.	Clino.			Ciliat.	
Eocene	Laevi.	?Dino.								
Paleocene										

satellacea, and the anterior muscle scar buttress of the upper Triassic *Septocardia* is foreshadowed by such groups of Carditacea as the Permophoridae during the Carboniferous. In spite of the strong resemblance of *Septocardia* to members of the cardiid line, Kafanov and Popov (1977) do not accept it as cardiid but jettison it by proposing a new family, "Septocardiidae Kafanov and Starobogatov *in* Kafanov and Popov," which they allocate to Tridacnacea, a Tertiary superfamily that has no firm record in the Mesozoic. May it not be, instead, that *Septocardia* is a link to the Carditacea through the genus *Palaeocardita* Conrad, 1867, which ranges throughout the Triassic? The genus *Septocardia* Hall and Whitfield, 1877, until recent years had been placed in Carditacea (see, for example, Vokes, 1967, p. 257). However, the reviser of Carditacea for the *Treatise on Invertebrate Paleontology*, André Chavan, rejected *Septocardia* from his list. His suggestion that the unit might belong in Cardiacea led me to examine it and accept the reallocation. If Chavan (*in* Moore *et al.*, 1969, p. N554) is correct in his interpretation of *Palaeocardita*, then many of the species now assigned to that unit by authors actually are *Septocardia*, and this genus was widely distributed in the Upper Triassic not only in the Americas but also in Europe. Specimens of *Septocardia* that I have seen from Alaska and Nevada exhibit a considerable variation in outline from quadrate to ovate, inequilateral to equilateral. The hinge has a distinctive anterior muscle scar buttress that is not shown at all in Chavan's figure nor mentioned by him in his diagnosis of *Palaeocardita*.

As I see it, the family may seem to be polyphyletic because the divergence from early ancestral stocks took place so far back in time that all the links have been obliterated. Thus, the subfamily Cardiinae seems to have two main branches — the *Septocardia-Cardium* line and the *Granocardium-Acanthocardia* line; the subfamily Protocardiinae, traceable almost as far back as *Septocardia*, shows resemblance only in the exaggerated size of the lateral hinge teeth but has a very different sculpture pattern. Two taxa within the Protocardiinae — *Nemocardium* and *Pratulum* — bridged that critical horizon between Cretaceous and Paleocene (called by some authors "the time of the great dying").

A New Zealand taxon, *Varicardium*, provides a good example of what appears to be iterative (*i.e.*, repetitive) evolution. Paleontologists of a century ago who were examining cardiids were content to say that *Protocardia, sensu stricto*, died out at the end of the Cretaceous everywhere except in New Zealand, for some species there had the *Protocardia* pattern of concentric sculpture anteriorly and radial sculpture posteriorly. However, with more knowledge of distribution and with a more critical evaluation of morphology, we now see that *Varicardium* is an offshoot of the *Nemocardium*

PLATE 8

Figures

1. *Trachycardium (Phlogocardia) belcheri* (Broderip & Sowerby). *Ex* Olsson, 1961. Rec., Ecuador (L ext. × 1)
2. *Trachycardium (Mexicardia) procerum* (Sowerby). SU specimen. Rec., Panama (R ext. × 0.5)
3. *Trachycardium (Dallocardia) senticosum* (Sowerby). With typical sculpture but not type species. *Ex* Olsson, 1961. Rec., Ecuador (R ext. × 0.8)
4. *Trachycardium (Conilocardium) cestum* (Dall). *Ex* Vokes, 1977. Mio., Florida (a, R ext.; b, L int.; × 1)
5. *Trachycardium (Trachycardium) consors* (Sowerby). *Ex* Olsson, 1961. Rec., Panama Typical sculpture but not type species. (L ext. × 0.8)
6. *Clinocardium (Clinocardium) nuttallii* (Conrad). SU specimen. Rec., Oregon (L ext. × 0.7)
7. *Nemocardium (Arctopratulum) griphus* Keen. Holotype, SU coll. Mio., Washington (R ext. × 1)
8. *Acrosterigma (Regozara) olivifer* (Iredale). Holotype, courtesy Australian Museum. Rec., Australia (L int. × 1)
9. *Clinocardium (?Keenocardium) californiense* (Deshayes). *Ex* Deshayes, 1841. Rec., N.W. Pac. (R ext. × 1)

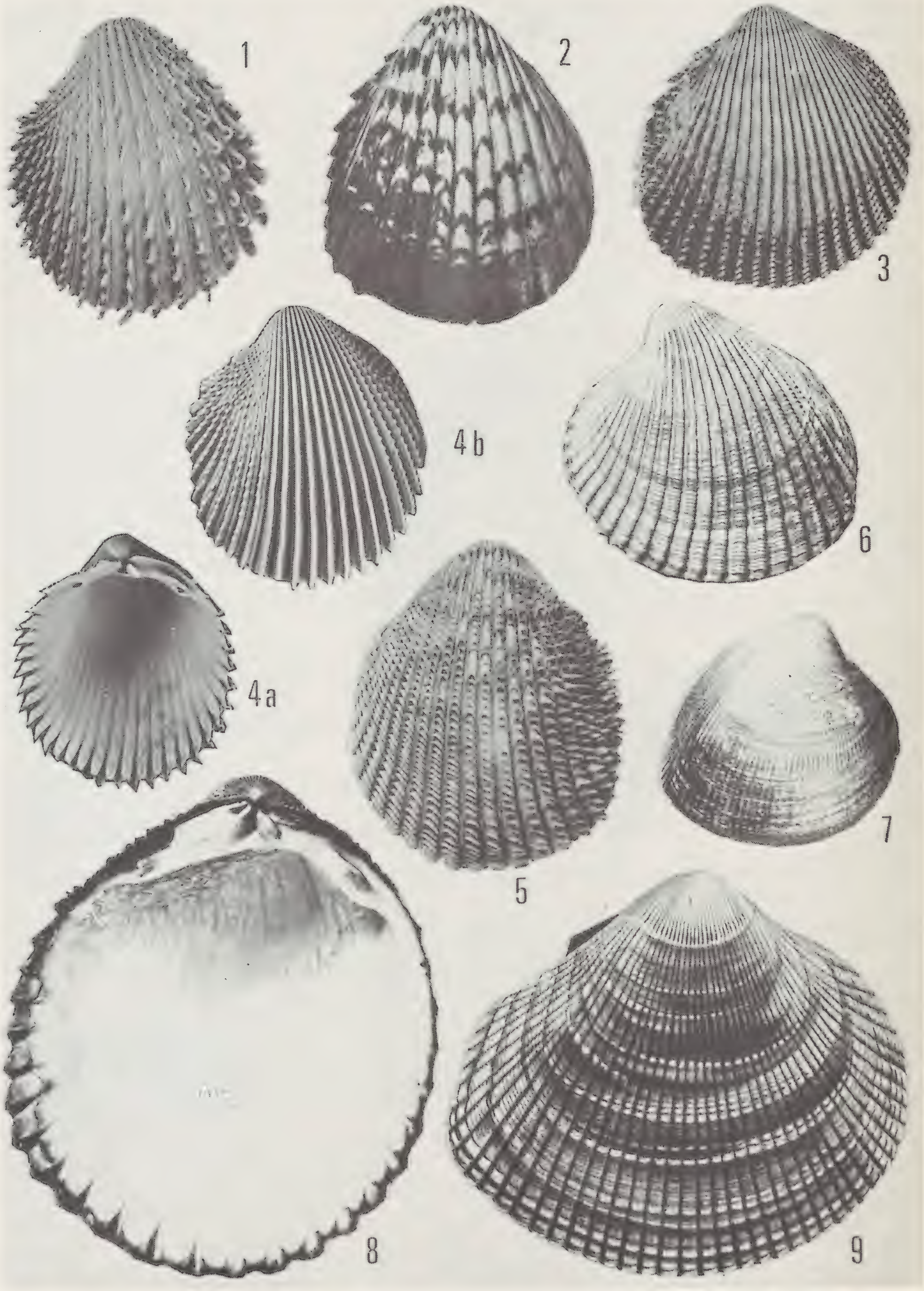


PLATE 8

line, branching off in the Miocene. The concentric folds of the anterior slope are irregular and superficial, not like the fine and regular costae of true *Protocardia*.

The relationships of the subfamily Hemidonacinae are unclear, for as yet it lacks a fossil record. Wilson and Stephenson (1977, p. 10) even defer acceptance of it in the family until more anatomical work is done. Derivation of the other three subfamilies from the two main Mesozoic stocks are fairly clear: Trachycardiinae and Fraginae branching off from the Cardiinae and Laevicardiinae from the Protocardiinae. The *Trachycardium* line is in general a New World counterpart of the Old World *Europicardium* stock. Fraginae show relationship to the *Acanthocardia* line in the sculpture of intercostal spaces and also, as Popov (1977) has shown, in the microstructure. The Laevicardiinae seem by definition to be diametrically opposite to Protocardiinae in the sculpture of the posterior slope, although in general outline and in the arched hinge there are affinities. One taxon in the Tertiary, *Habecardium*, bridges the gap between the two, for the juvenile shells have typical *Pratulum* ribbing, whereas the adults develop sculpture more like that of *Nemocardium*, except that the ribs of the posterior slope are not only without spines but may in part disappear, especially along the dorsal marin of the slope. Thus the shell comes to resemble *Laevicardium* so much that Glibert and Van de Poel, who named *Habecardium*, made it a subgenus of *Laevicardium* rather than of *Nemocardium*, where other workers had placed the several species.

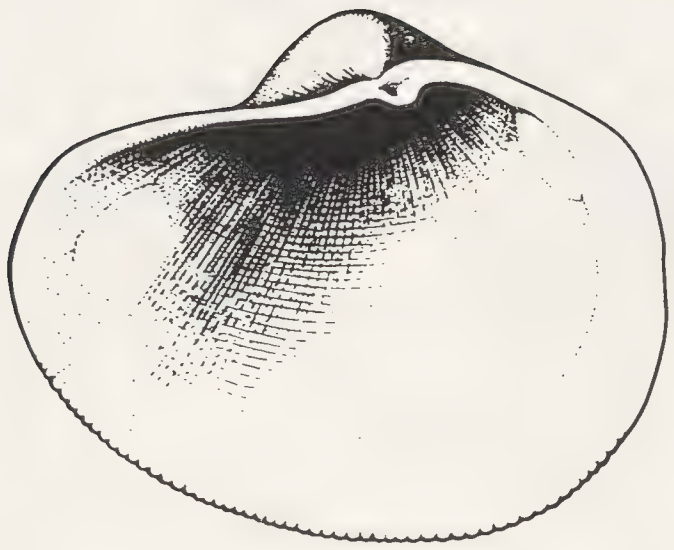
This, then, is a shadowy sketch of possible relationships of groups within Cardiidae. Until horizons are studied that now represent gaps, we can only speculate about the pathways of dispersal and the morphological adaptations of these mollusks. Newell (*in* Moore *et al.*, 1969, p. N213) summarized the whole matter very tersely: "Phylogenetic relationships are best deduced from the geologic history of the class, and this is poorly known."

PLATE 9

Subfamily Protocardiinae: interior view of left valves

Figures

1. *Nemocardium (Lophocardium) cumingii* (Broderip). CAS specimen. Rec., Colombia (× 2)
2. *Nemocardium (Pratulum) thetidis* (Hedley). SU specimen. Rec., Victoria, Australia (× 2.3)
3. *Nemocardium (N.) semiasperum* (Deshayes). SU specimen. Ypresian Eocene, France (× 1.5)
4. *Nemocardium (Microcardium) peramabile* (Dall). SU specimen. Rec., Gulf of Mexico (× 5)
5. *Protocardia (Pachycardium) spillmani* (Conrad). SU, plaster cast of topotype, courtesy USNM. U. Cret., Mississippi (× 0.5)
6. *Nemocardium (Lyrocardium) lyratum* (Sowerby). SU specimen. Rec., Japan (× 1)
7. *Protocardia (Leptocardia) subquadrata* (Evans & Shumard). SU specimen; hinge reconstructed from cast of other valve. U. Cret., Pierre shale, South Dakota (× 5)
8. *Protocardia (Tendagurium) propebanneiana* (Dietrich). U. Jur., E. Afr. Composite tracing from original figures, with hinge reconstructed from cast of other valve. (× 0.5)
9. *Integricardium (Onestia) onestae* (McLearn). From a plaster cast of holotype, SU coll. Cret., Alberta, Canada (× 1.4)
10. *Integricardium (I.) dupinianum* (Orbigny). Reconstructed hinge, from original figure of other valve. Cret., France (× 0.5)
11. *Protocardia (P.) hillana* (Sowerby). After Woods, 1908. L. Cret., England (× 1.2)
12. *Jurassicardium axonense* (Cossmann). From a syntype in the Cossmann coll., Sorbonne. Bathonian Jur., France (× 3.5)
13. *Nemocardium (Discors) parisiense* (Orbigny). SU specimen. Auversian Eoc., France (× 3)



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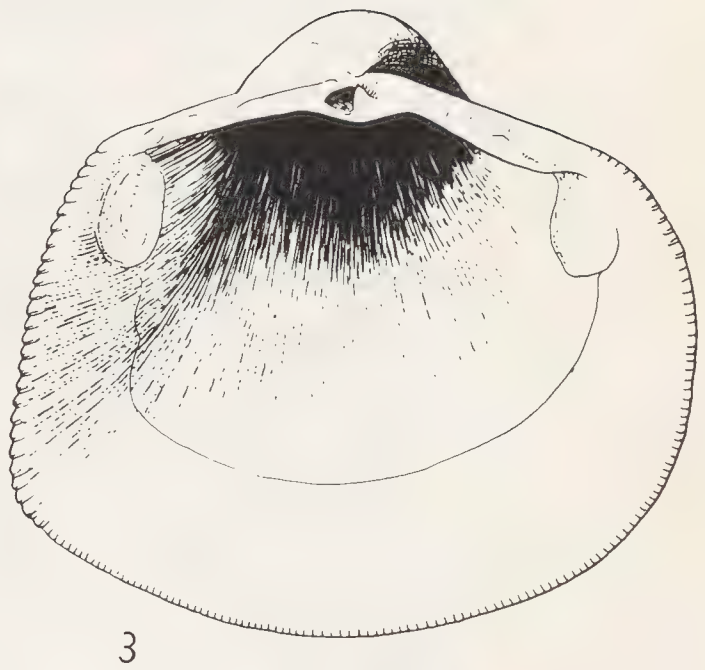

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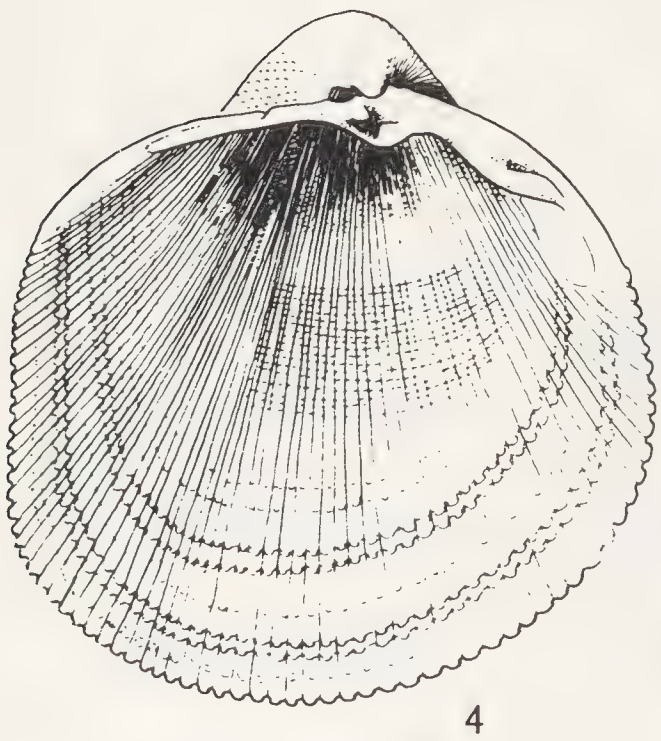

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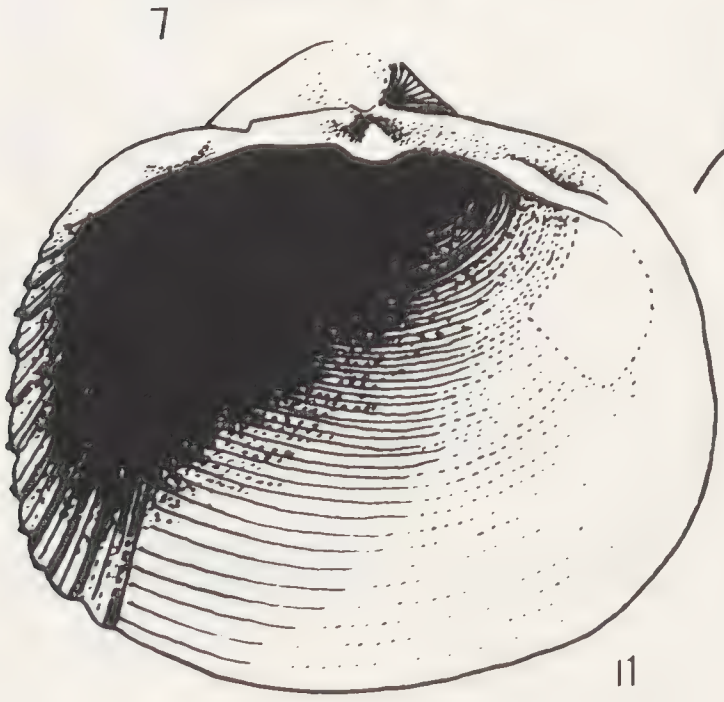

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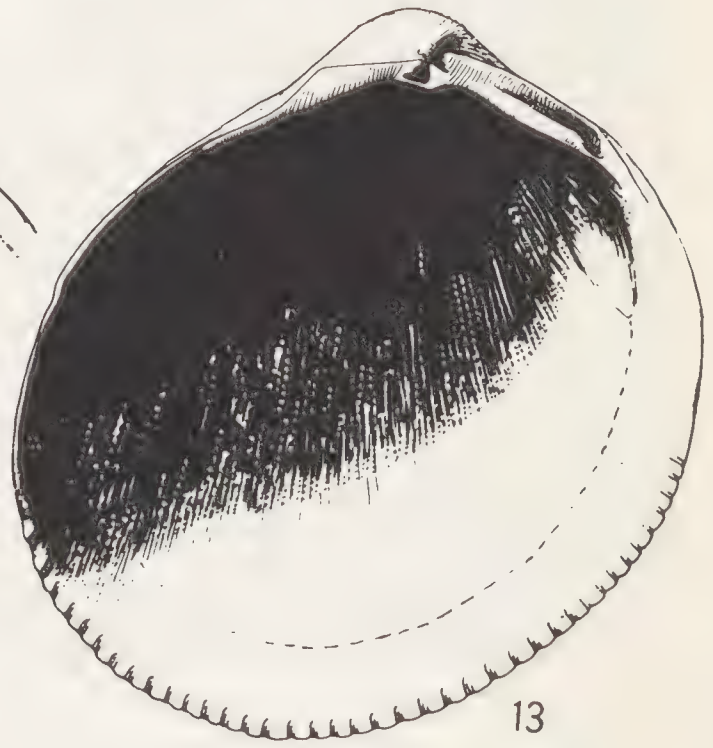

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PLATE 9

V. ABBREVIATIONS

Institutions

CAS	California Academy of Sciences, San Francisco
SU	Stanford University (collection now housed at California Academy of Sciences)
USNM	U.S. National Museum, Washington, D.C.

Geologic periods and other time terms

Cret.	Cretaceous
Eoc.	Eocene
Jur.	Jurassic
L.	Lower
M.	Middle
Mio.	Miocene
Neog.	Neogene (*i.e.*, Miocene/Pliocene, undifferentiated)
Oligo.	Oligocene
Paleoc.	Paleocene
Pleist.	Pleistocene
Plio.	Pliocene
R.,Rec.	Recent
Trias.	Triassic
U.	Upper

Geographic localities

Afr.	Africa
Am.	America
Atl.	Atlantic
Austral.	Australia
C. Am.	Central America
cosmop.	cosmopolitan (*i.e.*, present in all major seas)
E.	East
Eu.	Europe
Ind.	Indies
IndoPac.	Indo-Pacific
Medit.	Mediterranean
N.	North
N.Z.	New Zealand
Pac.	Pacific
S.	South
SE	Southeastern
US, USA	United States
W.	West

Systematic terms; morphologic terms

ex	from
ext.	exterior
ICZN	International Commission on Zoological Nomenclature
int.	interior
L	left (referring to left valve)
M	Monotypy (type designation)
OD	Original designation (type designation)
R	right (referring to right valve)
SD	Subsequent designation (type designation)
SM	Subsequent monotypy (type designation)
s. s.	*sensu stricto* (in the strict sense)
T	Tautonymy (designation by absolute tautonymy)

PLATE 10

Mesozoic Protocardiinae

Figures

1. *Jurassicardium axonense* (Cossmann). *Ex* Moore *et al.*, 1969. M. Jur., France (R ext. × 2)
2. *Protocardia (Protocardia) hillana* (Sowerby). *Ex* Moore, *et al.*, 1969. L. Cret., England (L ext. × 0.5)
3. *Protocardia (Brevicardium) fragilis* (Stephenson). 3a, b, d, after Stephenson, 1955; 3c, after Stephenson, 1941. U. Cret., Mississippi (a, R ext. × 5; b,d, L int., ext. × 6; c, L int. × 3)
4. *Cryptocardia bajocensis* Palmer. *Ex* Palmer, 1974. Outline showing position of internal ridges. Jur., France (× 0.5)
5. *Integricardium (Integricardium) dupinianum* (Orbigny). *Ex* Moore *et al.*, 1969, after Orbigny, 1844. Cret., France (a, R hinge; b, dorsal view of both valves; × 0.6)
6. *Protocardia (Yokoyamaina) hayamii* (Keen & Casey). *Ex* Hayami, 1972. Jur., E. Asia (× 1)
7. *Protocardia (Globocardium) sphaeroidea* (Forbes). *Ex* Palmer, 1974. Cret., England (a, outline, showing position of the internal ridge × 0.3; b, L int., arrow pointing to internal knob; c, ventral view, both valves, posterior area at right × 0.7)
8. *Protocardia (Globocardium) rothpletzi* Krenkel, 1910. After Dietrich, 1933. U. Jur., E. Afr. Figured by Dietrich as *Cardium (Tendagurium);* transferred to *P. (Globocardium)* by Palmer, 1974. (L int. × 0.5)

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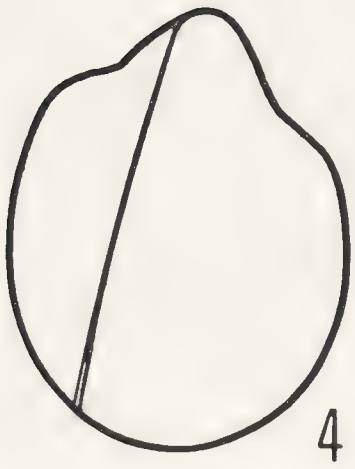

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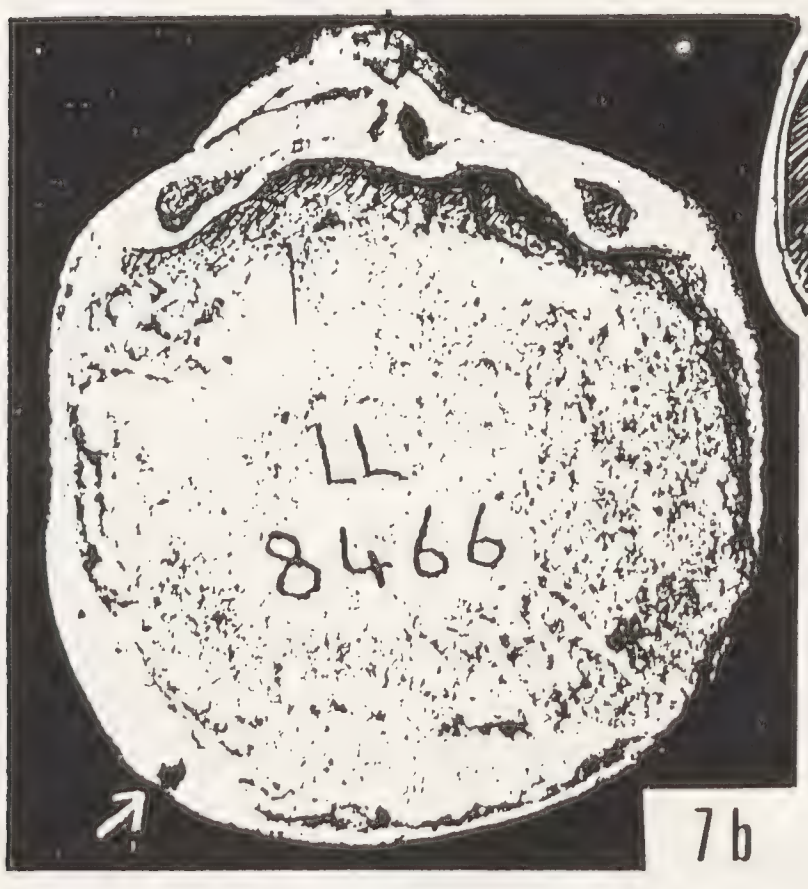

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PLATE 10

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PLATE 11

Cenozoic Protocardiinae

Figures

1. *Nemocardium (Keenaea) samarangae* (Makiyama). *Ex* Habe, 1951. Rec., Japan (L ext. × 1)
2. *Nemocardium (Frigidocardium) eos* (Kuroda). *Ex* Habe, 1951. Rec., Japan (L ext. × 1)
3. *Nemocardium (Trifaricardium) nomurai* (Habe). *Ex* Habe, 1951. Rec., Japan (L ext. × 1.5)
4. *Nemocardium (Divaricardium) discrepans* (Basterot). *Ex* Dall *in* Zittel, 1913. Mio., France (a, L int.; b, L ext.; × 1)
5. *Nemocardium (Arctopratulum) griphus* Keen. SU coll. Mio., Washington (a, L hinge; b, R hinge; × 1)
6. *Nemocardium (N.) semiasperum* (Deshayes). *Ex* Deshayes, 1858. Eoc., France (L ext. × 1)
7. *Nemocardium (Lyrocardium) lyratum* (Sowerby). *Ex* Chenu, 1862. Rec., E. Ind. (L ext. × 1)
8. *Nemocardium (Varicardium) patulum* (Hutton). *Ex* Marwick, 1944. Mio., N. Z. (R ext. × 0.7)
9. *Nemocardium (Pratulum) pulchellum* (Gray). Typical sculpure but not type species. *Ex* Marwick, 1944. Rec., N. Z. (R ext. × 2)
10. *Nemocardium (Habecardium) tenuisulcatum* (Nyst). Juvenile form: a, R int., b, R ext., c, detail of sculpture; *Ex* Deshayes, 1858, Oligo., France (× 1) Adult form, often identified as *N. cingulatum* (Goldfuss, 1837): d, L int., e, L ext., *ex* Von Koenen, 1893, Oligo., Germany (× 1)

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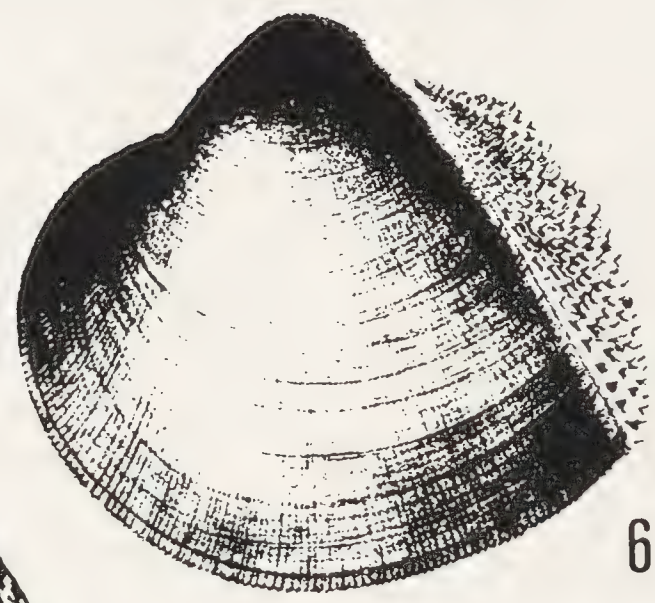

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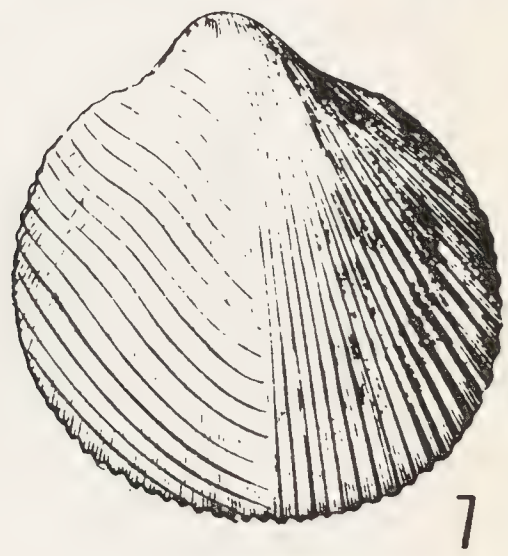

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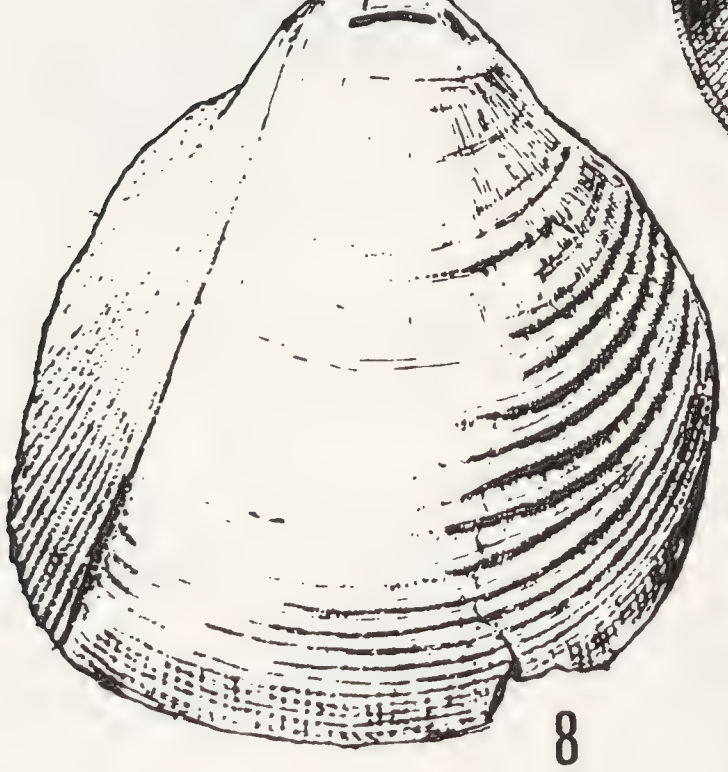

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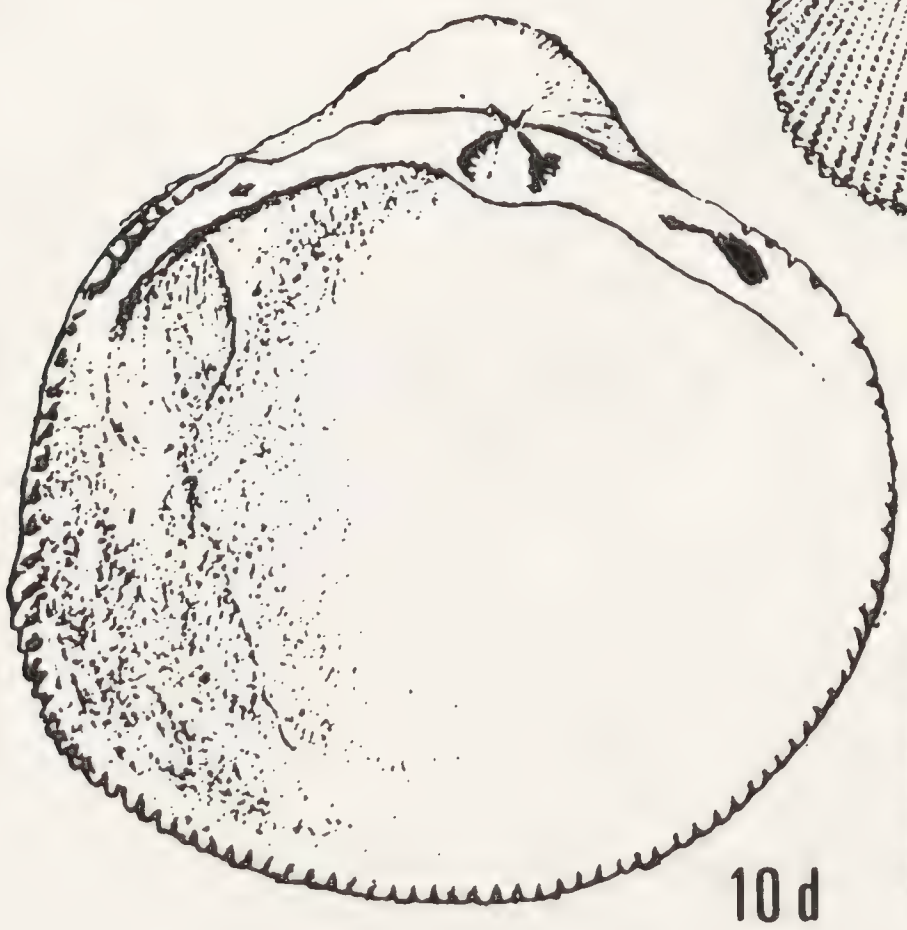

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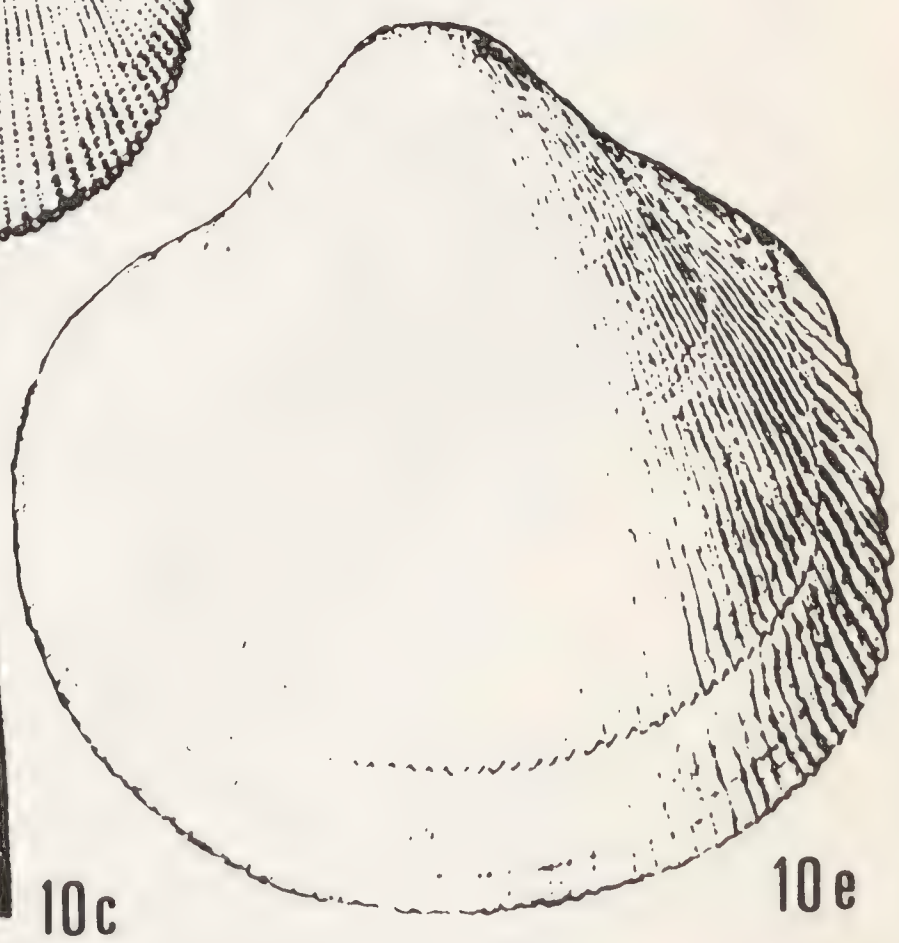

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PLATE 11

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VII. APPENDIX I

Commentary on a revision of Cardiidae by Fischer-Piette (1977)

Prof. Édouard Fischer-Piette has compiled the most extensive synonymies to be found in any modern work, on all of the species of living Cardiidae that he has been able to detect in the literature, and he has searched out and figured or refigured many type specimens in the collections of the British Museum (Nat. Hist.), the Paris Museum, and other European institutions. Also, he has named a number of new species. Following is a list not only of his innovations but also of the significant type material he has put on record. Each entry has this order of parts: specific name; original allocation; author; date; [allocation by Fischer-Piette, in square brackets]; locality; repository; commentary, if any; and, in capital letters, suggested reallocation to harmonize with the classification of the present paper.

aequale, Cardium, Deshayes, 1855; *[Corculum];* locality unknown; holotype, British Museum (Nat. Hist.).

auri, [Corculum (Trigoniocardia)], Fischer-Piette, 1977. Gulf of Guinea; Paris Museum. An extension of range of TRIGONIOCARDIA to the eastern Atlantic.

couvrili, [Laevicardium (Trachycardium)], Fischer-Piette, 1977. Gabon, W. Africa; Paris Museum. Probably ACANTHOCARDIA (EUROPICARDIUM), a first record in the Recent fauna.

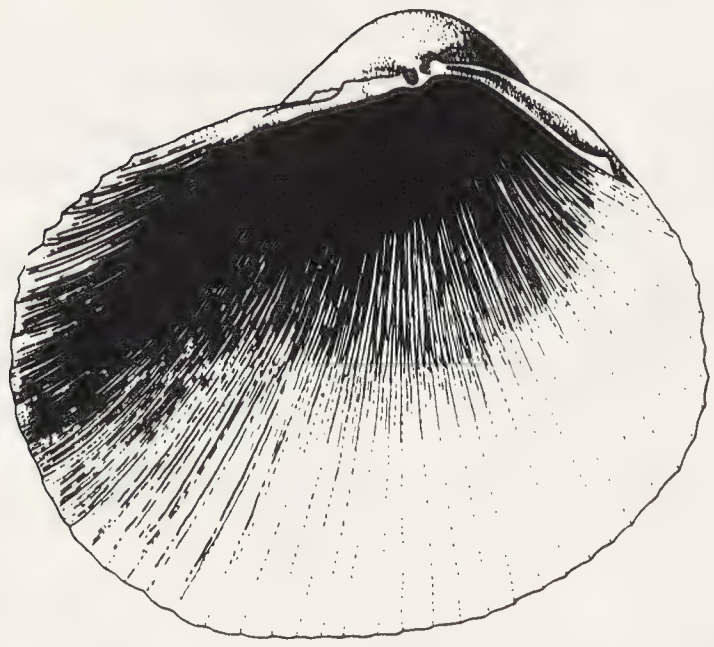
elongatum, Cardium, Bruguière, 1789; [=*Laevicardium (Trachycardium)* sect. *Acroterigma) leucostomum* (Born, 1780)]. Indo-Pacific. Specimen in the Lamarck coll., Geneva Museum. VASTICARDIUM ELONGATUM, type of *Vasticardium,* as shown by Vokes (1977, p. 160).

PLATE 12

Interiors of left valves, subfamily Laevicardiinae

Figures

1. *Laevicardium (Fulvia) apertum* (Bruguière). SU Coll. Rec., New Caledonia (× 1.5)
2. *Cerastoderma edule* (Linné). SU Coll. Rec., France (× 1.5)
3. *Clinocardium (C.) nuttallii* (Conrad). SU coll. Rec., Tillamook, Oregon (× 0.6)
4. *Laevicardium (L.) oblongum* (Gmelin). SU coll. Rec., Palermo, Sicily (× 0.75)
5. *Serripes groenlandicus* (Bruguière). SU coll. Rec. Icy Cape, Alaska (× 1)
6. *Laevicardium (Dinocardium) robustum* [Lightfoot]. SU coll. Rec., Florida (× 0.7)



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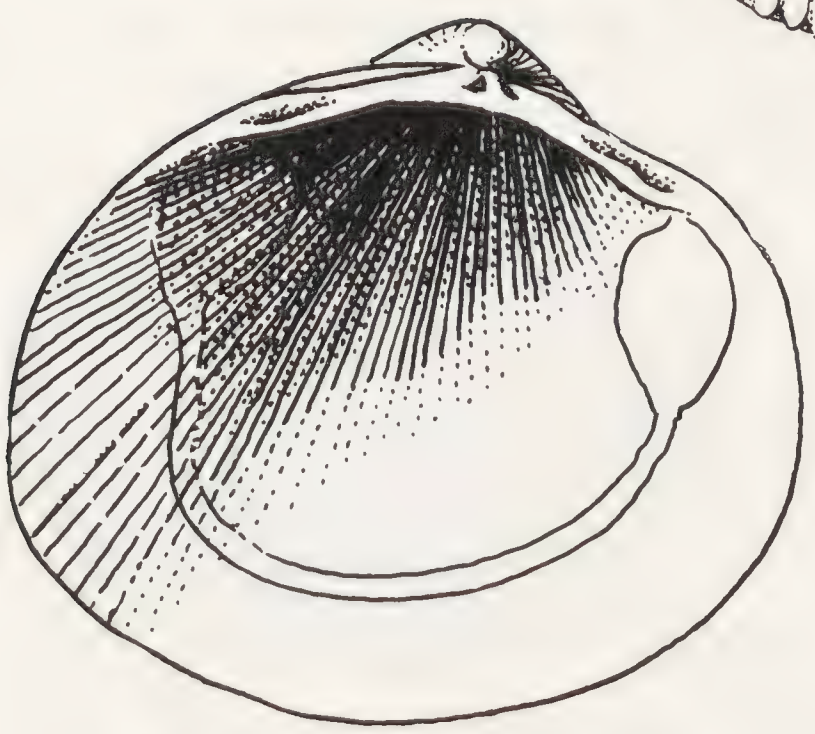

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PLATE 12

erinaceum, Cardium, Lamarck, 1819; [=*Cardium (Cerastoderma,* sect. *Acanthocardia) spinosum* Solander, 1786]. Mediterranean; holotype in Paris Museum. ACANTHOCARDIA (ACANTHOCARDIA).

*fimbriatum,Cardium,*Lamarck, 1819 (*non* Linné, 1758). Locality unknown; holotype, Paris Museum. Probably a juvenile specimen of VEPRICARDIUM ASIATICUM (Bruguière, 1789), as indicated by Lamy in 1941 (Bull. Mus. Nat. Hist. nat., Paris,ser. 2,v. 13, p. 459).

gaillardi, [Laevicardium (Trachycardium)] Fischer-Piette, 1977. New Zealand; Paris Mus. VASTICARDIUM. Locality may be open to question.

gratiosum, Cardium, Deshayes, 1855. [=*Laevicardium (Trachycardium,* sect. *Acrosterigma) enode* (Sowerby, 1834)]. Moluccas; syntype in British Museum (Nat. Hist.). ACROSTERIGMA (REGOZARA).

hiulcum, Cardium, Reeve, 1845; *[Papyridea].* Red Sea; specimen figured, Paris Mus. CTENOCARDIA (AFROCARDIUM).

hudsoniense, Cardium, Deshayes, 1855. [=*Corculum (Keenocardium) ciliatum* (Fabricius, 1780)]. Hudson Bay; possible holotype in British Mus. (Nat. Hist.). =PARVICARDIUM PINNULATUM (Conrad, 1831).

indicum, Cardium, Lamarck, 1819; *[Cardium (Cardium)].* Mediterranean area; Paris Mus., holotype.

interrogatorium, [Laevicardium], Fischer-Piette, 1977. California, Paris Mus. Probably =CLINOCARDIUM UCHIDAI (Habe, 1955), from the northwestern Pacific (not California); may be only a variant of *C. californiense* (Deshayes, 1839).

iranjanense, [Cardium (Cerastoderma, sect. *Parvicardium)],* Fischer-Piette, 1977. Madagascar; Paris Mus. FRAGUM.

lavrani, [Cardium (Cerastoderma)], Fischer-Piette, 1977. East Africa; Paris Mus. Probably PARVICARDIUM.

leucostomum, Cardium, Born, 1780; *[Laevicardium (Trachycardium,* sect. *Acrosterigma)].* Jamaica; holotype, Vienna Mus. VASTICARDIUM.

mauritianum, Cardium, Deshayes, 1855; [=*Laevicardium (Trachycardium,* sect. *Acrosterigma) enode* (Sowerby, 1834)]. Mauritius; syntype, British Mus. (Nat. Hist.). VASTICARDIUM.

nemo, [Laevicardium], Fischer-Piette, 1977. Locality unknown; Paris Mus., holotype. A fragmentary specimen resembling a fossil *Clinocardium* from the North Pacific.

"philippinense, Cardium, (Deshayes) Shirley, 1912" of Fischer-Piette, 1977, as *[Laevicardium (Trachycardium)].* Philippine Is.; specimen in Paris Mus. coll. *Nomen nudum* as of Shirley, 1912, and Tomlin, 1934; specimen evidently labelled by reference to a lot in the British Mus. coll. that carried only Deshayes' manuscript name. =VASTICARDIUM ORBITA (Sowerby, 1833).

productum, Cardium, Deshayes, 1855 (*non* J. Sowerby, 1832); [=*Corculum cardissa* (Linné, 1758]. Torres Straits; syntype in British Mus. (Nat. Hist.).

rudentis, [Laevicardium (Vepricardium)], Fischer-Piette, 1977. West Africa; Paris Mus. CARDIUM (BUCARDIUM).

serrulatum, Cardium, Deshayes, 1855; *[Laevicardium (Trachycardium)].* Guinea; possible holotype, British Mus. (Nat. Hist.). VEPRICARDIUM.

soyeri, [Laevicardium], Fischer-Piette, 1977. ?Mediterranean area; Paris Mus. Probably a VASTICARDIUM with incorrect locality data.

tertium, [Laevicardium], Fischer-Piette, 1977, new name for *Cardium fragile* Sowerby, 1834, *non* Brocchi, 1814. Locality unknown. LAEVICARDIUM (FULVIA).

thielei, [Laevicardium (Trachycardium)], Fischer-Piette, 1977, new name for *Cardium radula* Thiele & Jaeckel, 1931, *non* Broderip & Sowerby, 1829. Dar es Salaam, E. Africa. CTENOCARDIA (AFROCARDIUM).

PLATE 13

Cenozoic Laevicardiinae

Figures

1. *Cerastoderma edule* (Linné). *Ex* Moore *et al.*, 1969. Rec., Eu. (L ext. × 1)
2. *Laevicardium (L.) oblongum* (Gmelin). *Ex* Moore *et al.*, 1969. Rec., Eu. (R ext. × 0.5)
3. *Serripes groenlandicus* (Bruguière). *Ex* Chenu, 1862. Rec., N. Atl. (a, R hinge; b, L hinge; c, L ext.; × 1)
4. *Clinocardium (Planicardium) virginianum* (Conrad). *Ex* Olsson, 1967. Mio., Florida (a, juvenile shell, R int. × 1.2; b, juvenile shell, R ext. × 1)
5. *Clinocardium (C.) nuttallii* (Conrad). *Ex* Moore *et al.*, 1969. Rec., Oregon (R ext. × 0.5)
6. *Laevicardium (Profulvia) harrimani* (Dall). *Ex* Dall, 1910. Mio., N. Pac. (L ext. × 1)
7. *Clinocardium (Ciliatocardium) ciliatum* (Fabricius). *Ex* Sars, 1878. Rec., N. Atl. (R ext. × 1.5)
8. *Clinocardium (Fuscocardium) braunsi* (Tokunaga). *Ex* Oyama, 1973. Pleist., Japan (a, juvenile, L ext. × 1; b, adult, L int. × 1; c, adult, L ext. × 1)

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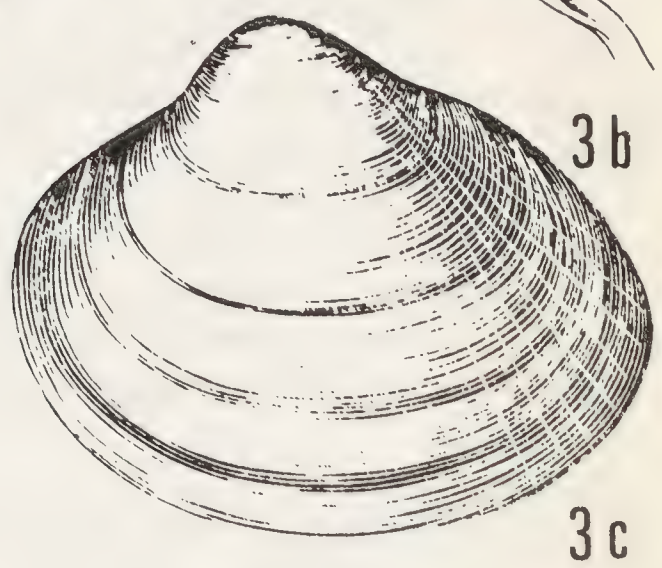

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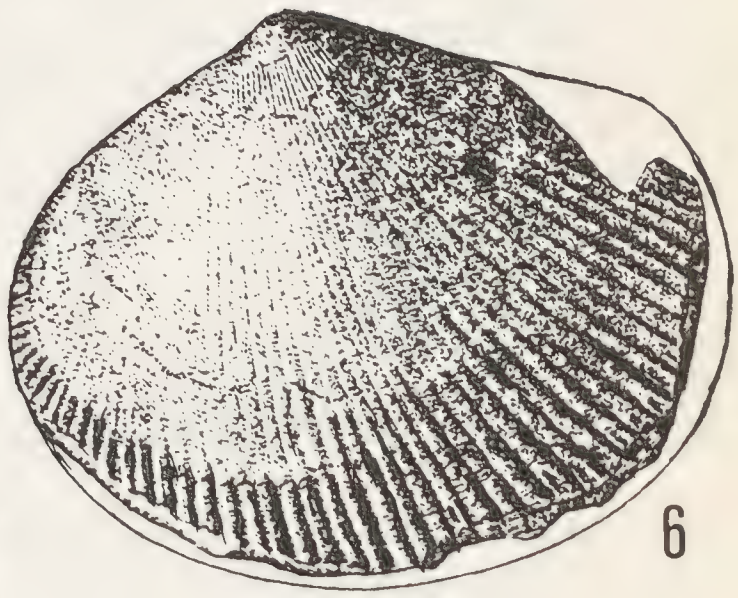

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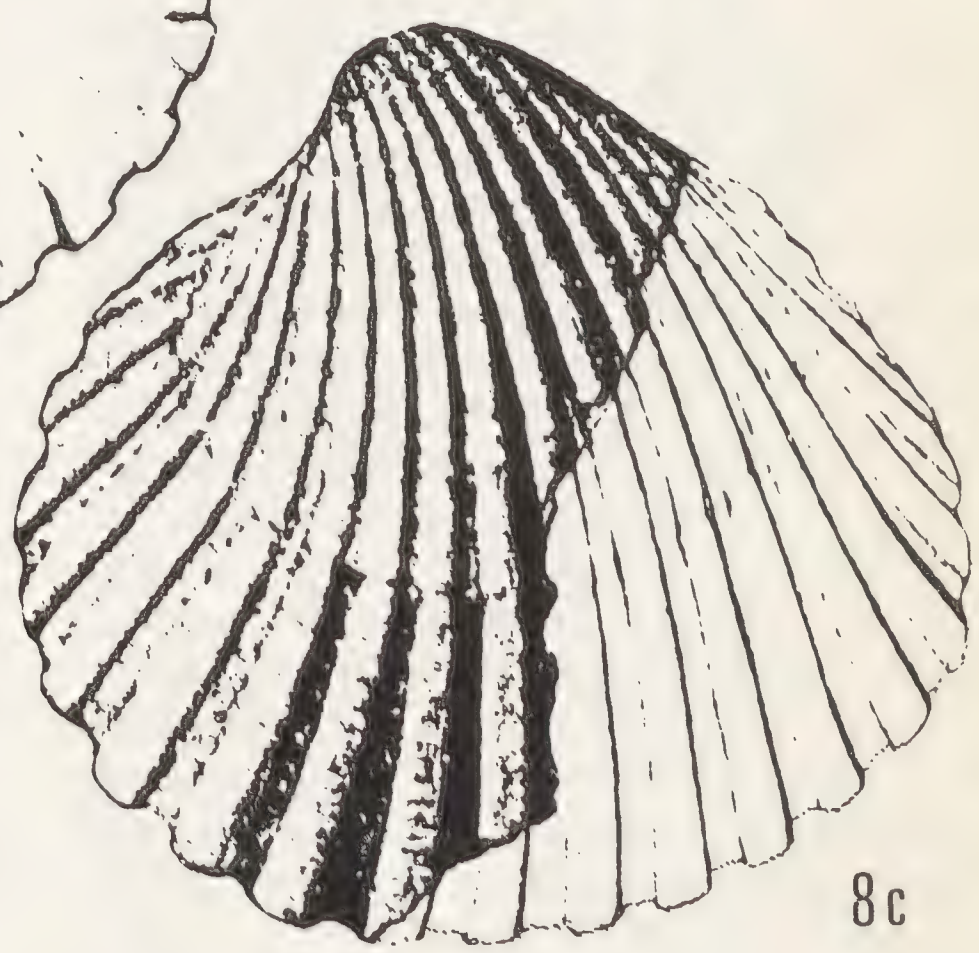

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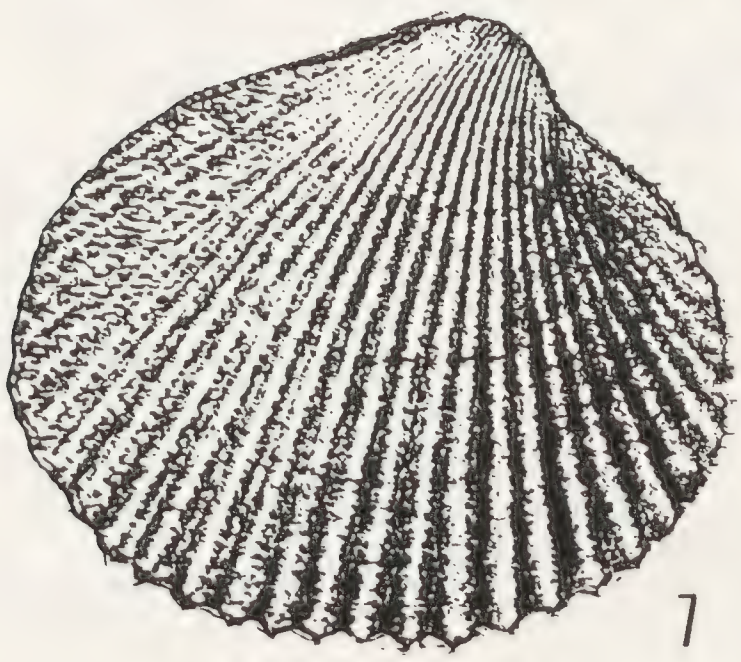

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PLATE 13

tumidum, Cardium, Deshayes, 1855 (*non* Kloeden, 1834). [=*Laevicardium (Trachycardium, sect. Acrosterigma) enode* (Sowerby, 1834)]. Moluccas; syntype, British Mus. (Nat. Hist.). ACROSTERIGMA (REGOZARA) sp.; not a synonym of *Vasticardium enode,* but it may fall within the range of variation of *A. (R.) gratiosum,* cited above.

vulva, Cardium, Jousseaume, 1898; [=*Corculum (Keenocardium) californiense* (Deshayes, 1839)]. Japan; holotype in Paris Mus. =CLINOCARDIUM BUELOWI (Rolle, 1896).

williami, [Microcardium] Fischer-Piette, 1977. Unnecessary new name for a supposed homonym: *Protocardia panamensis* Dall, 1908, versus *Cardium panamense* Sowerby, 1833, species that now fall not only in different genera but in different subfamilies.

Note: Fischer-Piette identifies as "*Laevicardium (Trachycardium) senticosum* (Sowerby, 1833)" a specimen collected by DuPetit Thouars, labelled as from "Monterey, California." He cites it on p. 54 and figures it on pl. 4, fig. 3 and pl. 5, fig. 1. It is instead TRACHYCARDIUM (DALLOCARDIA) QUADRAGENARIUM (Conrad, 1837) and is probably from southern California, near Santa Barbara or Los Angeles.

VIII. APPENDIX II

Placement of two new taxa named by R. W. Scott in 1978

In a paper that appeared only a short time after mine had been submitted for publication, Robert W. Scott proposed two new taxa in Cardiidae. He was, of course, unaware that I had in preparation a further review of the family. Even belatedly, I am glad to be able to incorporate them here, insofar as I can. I find it a satisfaction that these have been given formal status, for both taxa were among the hitherto unnamed groups that my literature search revealed as possibly distinctive. However, I find that he and I are not in complete agreement on where the taxa fall within the family. He allocates them to the Cardiinae on the basis of rib sculpture. The general outline and the heavy and arched hinges seem to me to point toward the Protocardiinae. Having seen only one small lot of specimens and not having had opportunity to review the matter thoroughly, I do not feel justified here in making a positive reassignment. Rather, I have added the two new names in the list of Section 1 but have deferred a final decision. Below are the modifications that would be required to fit the units into the keys for either of the subfamilies. Elsewhere in the text (Section 3 and Tables 2 and 5), I have included the names in both settings, with question marks. *Pleuriocardia* s. s. has some resemblance to *Protocardia (Brevicardium).* However, both *Pleuriocardia* s.s. and *P. (Dochmocardia)* may be offshoots of the *Nemocardium (Pratulum)* line, which also originated during the Lower Cretaceous. Dr. Scott considers the two taxa to be closer to the *Granocardium* line, with reduced sculpture.

Possible modification of key to Cardiinae to include two new taxa:

12. Shells medium-sized; cardinal teeth about midway between laterals 12a
    Shells mostly large-sized; anterior section of hinge shorter than posterior ..... MAORICARDIUM [16]

12a. Beading on rib crests well developed PLAGIOCARDIUM [15]
    Beading on rib crests weak to wanting .12b

12b. Shell nearly erect; beaks only slightly prosogyrate .....PLEURIOCARDIA [17a]
    Shell prosocline; beaks clearly prosogyrate DOCHMOCARDIA [17b]

Possible modification to Key to Protocardiinae:

22. With secondary concentric laminae throughout .....PRATULUM [63]
    Concentric laminae wanting or irregular or on posterior slope only 22a

22a. Secondary concentric laminae on posterior slope 23
    Secondary concentric laminae wanting or irregular 22b

22b. Ribs fine; shell nearly erect; beaks only slightly prosogyrate ..... PLEURIOCARDIA [65a]
    Ribs relatively coarse; shell prosocline; beaks clearly prosogyrate ..... DOCHMOCARDIA [65b]

PSEUDOCARDIA CONRAD, 1866, A DISREGARDED NAME IN CARDITIDAE

A. MYRA KEEN
STANFORD UNIVERSITY,
STANFORD, CALIFORNIA

Timothy Conrad, although a respected and knowledgeable paleontologist of the last century, was at times criticized by other authors for carelessness in some of his publications.* His enigmatic proposal of the generic name *Pseudocardia,* in an article on new taxa of Recent and fossil mollusks, is an example. Between a paragraph on the family Cyprinidae and one on Mytilidae, Conrad (1866, p. 103) had this:

> CARDITIDAE.
> PSEUDOCARDIA, Conrad.
>
> *C. Smidti,* Horn, *C. Hungaricum,* H., *C. Mageri,* H., *C. Haueri,* H., *C. apertum,* Munster, *C. conjugens,* Partch., *V. Neocomiensis,* D'Orb., *V. quadrata,* D'Orb., *V. tenuicostata,* Zittel, V. *Dupiniana,* D'Orb., *V. constantii,* D'Orb., *V. cottaldina,* D'Orb., *V. dubia,* Sowerby. A genus which became extinct in the upper Cretaceous Period.

No specific name was given in full. Nor was there any description of the genus *Pseudocardia* — only the statement that it was of Cretaceous age. One might logically assume the "*C.*" names to be intended as species in *Cardita,* but no such Cretaceous species have yet been identified by authors. Another interpretation will be discussed below. The "*V.*" names can all be recognized under *Venericardia,* a carditid genus, in the literature on the European Cretaceous. Some authors at that time used the names *Cardita* and *Venericardia* interchangeably.

Three years later Conrad supplied (1869a, p. 246) a clue to his concept of *Pseudocardia.* First he pointed out that the name might prove to be preoccupied by *Pseudocardium* Gabb, 1866, which had priority, and if so he proposed *Vetocardia* as a replacement. Then he gave a few lines of description, although he still cited no specific name completely. His statement, ". . the genus is evidently nearly related to *Astarte,* though d'Orbigny refers it to *Venericardia*", lends support to that interpretation of the "*V.*" names in his list.

Stoliczka (1871, p. 283), discussing *Pseudocardia,* commented: "Conrad called some of the Cretaceous species at first *Pseudocardia,* for which he subsequently substituted *Vetocardia,* as the type of which *Venericardia dupiniana* d'Orb. can fairly be taken." Most later workers have accepted this as a valid type designation. Cox (1946, p. 37, note), for example, wrote: "Stoliczka selected *Venericardia dupiniana* d'Orbigny as type," and Eames (1951, p. 342) said: "*Pseudocardia* Conrad, 1866 . . type species: *Venericardia dupiniana* d'Orbigny, Cretaceous; Stoliczka, 1871." According to Article 69 (a)(iii) of the ICZN Code, ". . an author is considered to have designated one of the originally included nominal species as type-species if he states that it is the type, for whatever reason, right or wrong, and if it is clear that he himself accepts it as the type-species." This provision in the Code would seem to be definitive for fixing *V. dupiniana* as type, either by Stoliczka's designation or by Cox' later acceptance of it.

The late André Chavan, reviser of the Carditacea for the "Treatise on Invertebrate Paleontology" (Chavan *in* Moore, 1969), did not, however, accept Stoliczka's designation as valid, for he regarded it as made in an ambiguous or qualified manner, rejectable under Article 67 (c) of the Code. He also did not accept the designations by Cox and by Eames, considering that they merely reflected Stoliczka's "somewhat casual mention of *Venericardia dupiniana*" (*ibid.*, p. N-553). Instead, Chavan read the "*C.*" names as *Cardium* and selected as type the first nominal species, which he characterized as, "presumed to be an erroneous citation of *Cardium schmidti* Hörnes." He may well have been correct in surmising that the "Horn" of Conrad's "*C.*" list might be a misspelling of "Hörn." [i.e., Hörnes]. In 1851 Moriz Hörnes had begun a large monograph on the fossil mollusks of the Vienna Basin, and by 1861 he had gotten up to the genus *Cardium.* Among the 30 species of this genus that he discussed, the

*A brief account of Conrad's life and a perceptive explanation for the apparent carelessness is given by Ellen J. Moore (1962, pp. 25-27).

six "*C.*" names listed by Conrad can be recognized (with a few minor spelling errors) as Hörnes' numbers 16, 17, 19, 22, 26, and 30 (in that order). Even if, however, Stoliczka's designation were invalid, Chavan's choice would be ill-advised, for Hörnes' species is a late-Tertiary form, which would make that selection contravene the single requisite of Conrad's original proposal: that *Pseudocardia* is a Cretaceous genus. Chavan in 1951 (p. 112) designated *Cardita dupiniana* as the type species of a new nominal taxon, *Ludbrookia*. This usage he continued in the "Treatise," only making the concession, in the face of protests by colleagues, that *Pseudocardia* might be relegated to the status of "*genus dubium.*" (Chavan, 1969, p. N-558).

Why would Conrad have bracketed the Tertiary *Cardium* species with the very different Venericardias he was placing in *Pseudocardia*? May it not be that, obviously having studied Hörnes' work, Conrad had sensed that there was here among the Cardiums an unrecognized generic taxon and that he had started to propose a name for it, selecting from among Hörnes' 30 species six that were to be included in the new group? Surely he would have headed such a paragraph "Cardiidae," for it is hard to believe that as astute a paleontologist as he would have allocated species of Tertiary Cardiidae into his new unit of Cretaceous Carditidae — surely not the Conrad who was at that very period, by virtue of his detailed knowledge of molluscan morphology and geological succession, successfully challenging Gabb's stratigraphic conclusions on a part of the California Cretaceous. The cardiid unit was indeed a good candidate for generic recognition, and it actually was given a name a few years later: *Lymnocardium* Stoliczka, 1870. Stoliczka designated as type species *Cardium haueri* Hörnes, which had been one of the names in Conrad's "*C.*" list. If this conjecture about Conrad's intention is correct, then he must have decided subsequently not to propose the cardiid unit and have deleted any discussion he had prepared. But the list of species did not get crossed out, and a typesetter may have been the one who incorporated it in an adjacent paragraph. Evidently Conrad did not notice this in the proofs, if proofs there were, but his carelessness shows up by his not having detected the error after publication and by not having called attention to it either in his next note on *Pseudocardia/Vetocardia* or later.

There was no ICZN Code with its clear definition of homonymy in Conrad's day. Under the provisions of the modern Code, *Pseudocardia* is available. Although he had proposed *Vetocardia* only tentatively, Conrad seems soon to have decided to abandon *Pseudocardia*. He set the stage for confusion in a second discussion of *Vetocardia* (1869b, p. 48). Here he elaborated on the description, repeating a part of the earlier one but adding details on the hinge of the opposite valve from a specimen he had just received. He identified the new find as his earlier-named species *Astarte crenalirata* Conrad, 1860, which he now allocated to *Vetocardia*. Again he characterized the genus as known only in Cretaceous strata. Later (1872, p. 52) he added yet another complication by emending *Vetocardia* to *Vetericardia* because of a supposed error. Such emendation is not allowable under the present ICZN Code, for Article 32 (a)(ii) requires that any error be detectable in the original proposal. Conrad, not having indicated his reason for choice of the name, would have had no evidence to prove that he had made a mistake in his spelling.

Stephenson (1941, p. 175), not realizing that the reference he was citing (Conrad, 1869b) was not Conrad's first proposal (1869a) of the generic name *Vetocardia*, designated *Astarte crenalirata* as type-species of *Vetericardia* (=*Vetocardia*). He was unaware that this species was not in Conrad's original list. For the taxon Stephenson was trying to recognize, which is indeed a distinct unit morphologically, Chavan supplied another name, *Vetericardiella* (Chavan *in* Moore, 1969, p. N-552).

Confusion has continued, and the unneeded generic name *Ludbrookia* is finding its way into the literature on Cretaceous carditids (*e.g.*, Scott, 1977) because of its seemingly legitimate use in the "Treatise."

Even at the time the "Treatise" revision appeared, there was available another assessment of carditid taxonomy, a compilation done independently by H. E. Vokes (1967, p. 257). Here Vokes listed *Pseudocardia* Conrad as the valid name for a carditid unit, with *Vetocardia*, *Vetericardia*, and *Ludbrookia* as synonyms.

One may well ask what action now would best promote nomenclatural stability. Chavan was unwilling to petition the ICZN for suppression of *Pseudocardia*. Under the present rules, it is not a homonym of *Pseudocardium*, differing by more than one letter, and it also differs by the necessary one letter from *Pseudocardita* Oppenheim, 1918, a group in Cardiacea. Although *Pseudocardia* has not been used for the last century as a generic name, it does not qualify as a *nomen oblitum* (forgotten name), nor do the two satellites *Vetocardia* and *Vetericardia*, for authors have been aware of them, and all have been senior to the junior synonym *Ludbrookia* much less than the required 50 years. Suppressing the three in favor of *Ludbrookia* would be an easy way out of the dilemma, but that course might be less than acceptable to the ICZN Commission. In the matter of the type-species of *Lucina* (Opinion 1095, Nov. 1977), the Commission rejected an attempt to give legal status to another of Chavan's taxonomic usages. Their ruling made clear that mere convenience does not justify use of the plenary powers when the basic issue involves a misapplication of the provisions of the Code.

The following synonymy therefore is suggested here for the names discussed. It is congruent with the published recommendations of Vokes (1967).

Family CARDITIDAE

PSEUDOCARDIA Conrad, 1866 (Apr.) [type species, *Venericardia dupiniana* Orbigny, 1843 (plate expl.) =*Cardita dupiniana* Orbigny, 1844 (text); SD Stoliczka, 1871 (accepted by Cox, 1946)] [=*Vetocardia* Conrad, 1869 (*nom. van.*); *Vetericardia* Conrad, 1872 (*nom. van.*); *Ludbrookia* Chavan, 1951 (obj.; OD)]. [Not to be confused with *Pseudocardium* Gabb, 1866 (Mactracea) nor with *Pseudocardita* Oppenheim, 1918 (Cardiacea)].

VETERICARDIELLA Chavan *in* Moore, 1969 [type species, *Astarte crenalirata* Conrad, 1860; OD]. [="*Vetericardia* Conrad" of Stephenson, 1941, not of Conrad, 1872].

Superfamily CARDIACEA
Family LYMNOCARDIIDAE

LYMNOCARDIUM Stoliczka, 1870 [type species, *Cardium haueri* Hörnes, 1861; OD].

PSEUDOCARDITA Oppenheim, 1918 [type species, *Cardium bukowskii* Oppenheim, 1918; SD Keen, 1937].

Superfamily MACTRACEA
Family MACTRIDAE

PSEUDOCARDIUM Gabb, 1866 (Feb.). [type species, *Cardium gabbii* Rémond, 1863 (= *Mulinia densata* Conrad, 1857); M].

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PYGMAEPTERYS, A NEWLY DESCRIBED TAXON OF MURICIDAE (MOLLUSCA: GASTROPODA), WITH THE DESCRIPTION OF THREE NEW SPECIES FROM THE CENOZOIC OF THE WESTERN ATLANTIC

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I. ABSTRACT

"Murex" alfredensis Bartsch, 1915, has recently been named as the type species of a new subgenus *Pygmaepterys* Vokes, 1978, along with a second species, *P. maraisi*, described at the same time. *"Murex" funafutiensis* Hedley, 1899, is here tentatively assigned to the same subgenus and three new species are described: *?Pygmaepterys germainae*, from the Recent and fossil fauna of the Caribbean; and *P. pratulum* and *?P. drezi*, from the Miocene Chipola Formation of northwestern Florida.

The subgenus was initially assigned to the genus *Pterynotus* in the subfamily Muricinae but *?P. germainae* proves to have a radula that indicates placement in the subfamily Muricopsinae. The unanswered question is whether *P. alfredensis*, *P. maraisi*, and *P. pratulum*, n. sp., are congeneric with *?P. funafutiensis*, *?P. germainae* and *?P. drezi*, n. sp., or whether the latter are members of a superficially similar genus-group in the Muricopsinae, distinct from *Pygmaepterys*.

II. INTRODUCTION

The smaller species of Gastropoda are among the least well-known members of any fauna and, thus, it is not surprising to find an entire group of small muricids that has been virtually overlooked, although, as this paper will demonstrate, there are at least four Recent and two fossil species. The present geographic range of this group is essentially world-wide tropical, reflecting a geologic history that extends back to the lower Miocene.

Two of the Recent species have been described many years but their affinities were not evident. Vokes previously (1971, p. 14 and 51, respectively) referred *"Murex" alfredensis* Bartsch, 1915, to *Dermomurex* and *"Murex" funafutiensis* Hedley, 1899, to *Pazinotus*. Radwin and D'Attilio (1976, p. 148) placed *M. funafutiensis* in *Favartia* and *M. alfredensis* in Incertae Sedis (*ibid.*, p. 215). Otherwise neither species has received any notice at all.

Our interest in this small group of inconspicuous (and rare) shells was engendered

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by a remarkable case of what can only be extreme parallelism between two species, one in the lower Miocene Chipola Formation of Florida and the other in the Recent fauna of South Africa. Among specimens sent to Vokes for identification by Richard N. Kilburn, of the Natal Museum, were examples of a tiny form, obviously related to *"Murex" alfredensis* but not the same. At first sight it appeared to be the twin of an undescribed species from the Chipola Formation, so similar in overall aspect were the two shells. Further work indicated differences, primarily in the protoconch, but the likeness is still amazing (compare pl. 1, fig. 6 and pl. 2, fig. 3). Also included in the same material was apparently the second known example of *"Murex" alfredensis* (see pl. 2, fig. 1).

Needless to say, here was an irresistible area for further research. Examination of *M. alfredensis* indicated that the *Dermomurex* assignment was no longer tenable, but no alternative was available. With the added evidence of other undescribed species, both in the African fauna and in the Caribbean, as well as two Chipola fossil forms, a new subgenus *Pterynotus (Pygmaepterys)* was erected, with *M. alfredensis* as type, inasmuch as it was the only previously described species. The second African species was named at the same time (Vokes, 1978).

Subsequent work brought about the recognition of *Murex funafutiensis* as a third Indo-Pacific member of the group. Six specimens sent to D'Attilio by a collector for identification proved to be examples of *"M." funafutiensis*. All were dredged in coralline algae and sand, at 100 fms., in Pokai Bay, Oahu, Hawaii. One of the specimens is figured here (pl. 2, fig. 5) and it can be seen that it resembles *Pygmaepterys alfredensis*, with the exception of several small denticles on the inner lip.

As noted above, Vokes had considered this form to belong to another little-known subgenus *Pazinotus* Vokes, 1970, which has a superficial resemblance to *Pygmaepterys*. However, the members of *Pazinotus* (type: *"Eupleura" stimpsonii* Dall) have a smooth shell and are considered members of the genus *Poirieria; Pygmaepterys* may be distinguished by the elaborate axial laminae and spiral cords covering the shell. The two groups share the trait of having more than three varices (four to seven in *Pazinotus*, six to nine in *Pygmaepterys);* but the surface ornamentation, which is perhaps the most conspicuous feature of *Pygmaepterys*, is almost totally lacking in *Pazinotus*. If *Pazinotus* (as the name implies) looks like a cross between *Pterynotus* and *Paziella*, then *Pygmaepterys* might be said to resemble a cross between *Pterynotus* and *Favartia* (hence, Radwin and D'Attilio's assignment for *M. funafutiensis).*

The unusually scabrous shell surface in *Pygmaepterys* lends an air of similarity to the members of the Muricospinae (see Radwin and D'Attilio, 1971, p. 64), especially the genera *Favartia* and *Murexiella*. Except for this ornamentation the shells otherwise seem much more closely akin to the muricine genus *Pterynotus* Swainson (type: *Murex pinnatus* Swainson*). Although many members of *Pterynotus* are smooth, the type species has a scabrous surface.

The resemblance to the Muricopsinae is primarily in the scabrous surface, composed of myriad axial growth lamellae. The nature of the aperture is different from most muricopsine genera. In *Murexiella* and *Favartia*, the two groups most likely to be confounded with *Pygmaepterys*, it is almost

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*The use of the name *Murex pinnatus* for this species has once again been sanctioned by the International Commission on Zoological Nomenclature. Technically, the name *Purpura alata* Röding, 1798, is older, but for years was assumed to be a secondary homonym of *Murex alatus* Gmelin, 1791, when both forms were referred to the genus *Murex s.l.* Only in the last few years have authors attempted to replace the long established *pinnatus* with the older but unused *alata*, because the International Code of Zoological Nomenclature took a very hard line on *nomina oblita* and demanded application to the Commission to conserve any threatened name. However, after long years of debate the Rules were amended (1974, Bull. Zool. Nomen., v. 31, pt. 2, pp. 77-89) and it was determined that "the Law of Priority is to be used to promote stability and is not intended to upset a long-established name" (Art. 23a-b) and, more importantly, that "a junior secondary homonym rejected before 1961 [as was *alata*] is permanently rejected and cannot be restored" (Art. 59b). The mills of the Commission grind slowly, but they ultimately grind very well, and *Murex pinnatus* is no longer *allowed* to be replaced by *Purpura alata* without petitioning the Commission.

circular, having only small, usually paired, elongate denticles on the inner side of the outer lip, and none on the inner lip. *Muricopsis* has a denticulated aperture similar to that of *Pygmaepterys* but otherwise the shells are little alike. *Murexiella* may have shoulder spines similar to *Pygmaepterys* but *Favartia* has virtually none; however, *Favartia* has the more elaborate axial growth lamellae. None of the Muricopsinae have the varical formation of *Pygmaepterys*, in which the abapical face of the varix is distinctly set apart as a separate flange. This type of varix formation is masked by the axial lamellae when the shell is fresh but is easily seen when the shell is worn (as in the specimen of *P. alfredensis*, pl. 2, fig. 1). Then the varices have a marked *Pterynotus*-like aspect. The same sort of varical formation is also to be seen in *Chicoreus (Naquetia)*, one of the reasons Vokes formerly thought that subgenus was more closely related to *Pterynotus* than it apparently is.

From the above discussion it is obvious that there is no one morphologic trait that may be used to identify positively any genus-group within the Muricidae. Each unit is rather a combination of the same limited variety of characteristics, but with a sum total that differs from that in any of the others. The radula and the operculum are the best means of differentiating between subfamilial groupings, but even they are by no means absolute. For example, the genus *Homalocantha* has a purpuroid operculum, but it belongs with either the Muricopsinae (on the basis of shell morphology and phylogeny) or the Muricinae (on the basis of the radula).

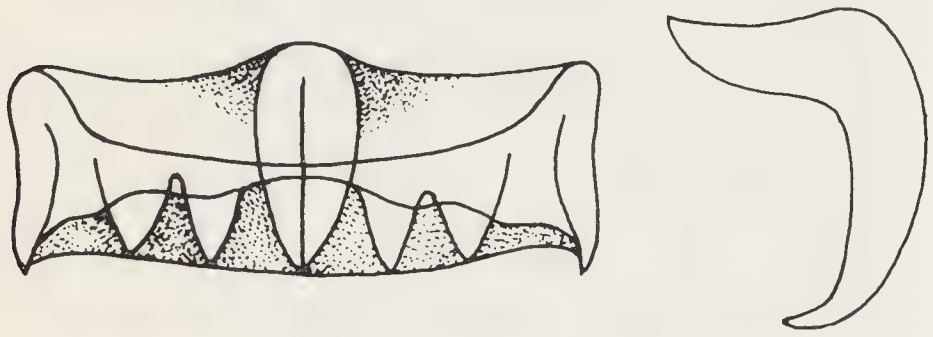
As of this writing there are three described species that may be referred to *Pygmapterys* — *alfredensis*, *funafutiensis*, and *maraisi* Vokes, the second African species (see pl. 2, fig. 3). Another possible member of the group is *Favartia kurodai* Nakamigawa and Habe, 1964, from Japan. This species superficially resembles "*M.*" *funafutiensis*, but with five varices per whorl (*M. funafutiensis* has seven) and less pronounced varical spines at the shoulder. The shell is more elongate than any of the other species here assigned to *Pygmaepterys;* nevertheless, in overall aspect it seems closer to the latter than to *Favartia*, where it was originally described.

All of the above are Indo-Pacific forms. However, there is an undescribed species in the waters of the Caribbean, with examples known from Puerto Rico to the coast of Panamá and also in the Miocene of the Dominican Republic and the Pleistocene beds of Costa Rica. Undoubtedly, once described it will be recognized in collections mis-labeled as "*Favartia cellulosa* (Conrad)." In addition, there are two fossil species from the late lower Miocene Chipola Formation of Florida. Like their modern counterparts these fossil species are not only small but rare, even in the Chipola Formation where size has no effect on the collecting, which is done in bulk, then washed and picked under a microscope. Their rareness is not just a function of being overlooked, as it may well be in the Recent fauna. In spite of the (literally) tons of material washed and picked from 56 localities over the last 20 years only 15 specimens of two species have been recovered.

Within this small group of species there are two major divisions. (One would like to use the word "species-groups," but that term has been preempted by the International Commission for a different meaning.) The first includes the two Recent African forms and one of the Chipola fossils, *P. pratulum*, n. sp. This group has no denticles on the inner lip and is the more *Pterynotus*-like morphotype. It is the one that includes the type species. The second group consists of *P. funafutiensis*, the Recent Caribbean *P. germainae*, n. sp., and the other Chipola fossil form, *P. drezi*, n. sp. In this morphotype there are denticles on the inner lip; the shell is less elongate and more *Favartia*-like. In spite of these differences the writers feel that the two groups are sufficiently similar to be included within the limits of one subgenus.

However, if all of these species are to be referred to the same genus-group, then the original assignment to *Pterynotus* and the subfamily Muricinae is incorrect, for the radula of the Caribbean *P. germainae* is that of the Muricopsinae (see text fig. 1). Thus, we are confronted with a problem that at this time cannot be resolved. Are we, in fact, seeing another of the instances of parallelism that mark the Muricidae, such as that presented by *Pterynotus* and *Pteropurpura*, both of which have three winged varices and appear, at first glance, to be

congeneric? Closer examination of the shells of these two genera reveals a difference in the open vs. sealed siphonal canal and, if one is fortunate enough to obtain the soft parts, different opercula and radulae. At this time we have no soft parts for any of the unquestionable species of *Pygmaepterys*. The soft parts of *P. germainae* indicate that it is undoubtedly a member of the Muricopsinae.



Text figure 1. Radula of *?Pygmaepterys germainae*, n. sp. Paratype B, SDNHM 71305; Grenada, W.I.

The recent report by Houart (1979) of another specimen from the Indian Ocean (here figured, pl. 2, fig. 2) that is very closely related to *P. alfredensis*, and may well be the first known adult of that form, strengthens the impression of the *Pterynotus* affiliation, for it looks most like a six-varixed *Pterynotus*. But it also has denticles on the inner lip, thereby removing the main conchological difference we have noted between these two "groups." More subtle differences that may be observed include a slightly greater number of denticles on the outer lip in the unquestioned *Pygmaepterys* species *(alfredensis, maraisi* and *pratulum)* and a more elongate shell. Also, there is no tendency to abort varices on the last whorl. However, these may well be only specific differences. Certainly, greater degrees of difference than this prevail in many other subgenera of the Muricidae. If these are only conchological differences they can be ignored. But if future work confirms the muricine affinities of the type species of *Pygmaepterus*, then we must concede that this is another of the cases of parallelism in the family.

Until such a time as soft parts are obtained for *P. alfredensis* there is no certain way we can determine whether or not the taxon *Pygmaepterus* should be referred to the subfamily Muricinae, and should comprise only a part of the species here treated, with the others being transferred to a new taxon in the subfamily Muricopsinae, or whether all of the species are members of the Muricopsinae. If all are muricopsine then the taxon should be considered as a subgenus of *Favartia:* if muricine, then *Pygmaepterys* should continue to be allied with *Pterynotus* as before. For the present study we will treat it as a full genus, with the subfamilial assignment only tentative.

III. ACKNOWLEDGMENTS

We wish to thank Richard N. Kilburn, of the Natal (South Africa) Museum, who originally provided the specimens of *Pygmaepterys* that prompted this study; Mrs. Germaine Warmke, Gainesville, Florida, who provided much of the type lot of *P. germainae*, n. sp.; Mr. and (the late) Mrs. Robert C. Hoerle, West Palm Beach, Florida, who collected many of the Chipola specimens, including the holotype of *P. pratulum*, n. sp.; Paul Drez, Houston, Texas, who contributed the holotype of *P. drezi*, n. sp.; Dieter Cosman, Huntington, N.Y., who provided three examples of *P. germainae* with dried soft parts that permitted the radular determination to be made; Richard Salisbury, U.S. Navy, who loaned the specimens of *P. funafutiensis;* and finally Roland Houart, of Ezemaal, Belgium, who loaned the Indian Ocean specimen of *P. (?)alfredensis*.

IV. SYSTEMATIC DESCRIPTIONS

Family MURICIDAE

? Subfamily MURICOPSINAE

Genus PYGMAEPTERYS Vokes, 1978

Pygmaepterys E. H. Vokes, 1978, Ann. Natal Museum, v. 23, no. 2, p. 398.

Type-species: *Murex alfredensis* Bartsch, 1915, by original designation.

? PYGMAEPTERYS DREZI
Vokes and D'Attilio, n. sp.
Plate 1, fig. 5

Diagnosis: Shell large for the group; with five post-nuclear whorls; protoconch unknown. Spiral ornamentation consisting of two major cords on the first and succeeding post-nuclear whorls; with on the body whorl five strong cords and, in

addition, one or more intercalary minor cords. On the short siphonal canal another two major cords and some minor cords. Axial ornamentation of narrow recurved varices, eight in number on each whorl before the adult body whorl; there every other varix tending to be obsolete — only six varices on the body whorl of the holotype with intervarical nodes replacing the "lost" varices. Adapical edge of each varix flexed toward the aperture, reflecting the posterior expansion of the columellar lip. Spiral cords crossing the varices forming short spinelets, largest at the shoulder. Adapertural faces of the varices covered by numerous minutely crenulate lamellae; in addition, intervarical areas crowded with crenulate axial growth lamellae. Aperture oval, inner side of outer lip with six denticles, corresponding to the areas between the spiral cords. Inner lip smooth, appressed, with a wide expansion at the posterior end and three small denticles at the anterior end. Siphonal canal short, broad, slightly recurved at the distal end; former terminations making a small fasciole.

Dimensions of holotype: height 11.8 mm, diameter 7.0 mm.

Holotype: USNM 294289.

Type locality: TU 546, Ten Mile Creek, about 1¾ miles west of Chipola River (NE ¼ Sec. 12, T1N, R10W), Calhoun County, Florida.

Occurrence: Chipola Formation, late lower Miocene; Florida.

Figured specimen: USNM 294289 (holotype). Other occurrences: TU locality no. 830.

Discussion: This new species is unquestionably the ancestor of *P. germainae,* n. sp., the Recent Caribbean form described below. The principal difference between the two is size, *P. drezi* being almost twice the size of the Recent form. (Note that the magnification of most of the figures of *P. germainae* is × 8 but *P. drezi* is × 4). In addition, there is one more varix per whorl in *P. drezi* (eight instead of seven) and the shell is more elongate than in *P. germainae*. However, the resemblances between the two are remarkable, considering the difference in the geologic ages. Whether or not mature examples of *P. drezi* show the *posterior* labial denticles of *P. germainae* must await discovery of more material. None of the three examples of *P. drezi* now in hand do have them, but then, many specimens of *P. germainae* do not either.

Pygmaepterys pratulum
Vokes and D'Attilio, n. sp.
Plate 1, figs. 6, 7

Diagnosis: Shell large for the group, with six post-nuclear whorls and a protoconch of two and one-half somewhat bulbous whorls. Spiral ornamentation beginning with first one, then two strong cords, and a faint third at the shoulder, increasing to seven on the body portion of the last whorl and several smaller cords on the siphonal canal. Axial ornamentation of nine lamellar varices on each whorl except the last where there are only six to eight, with no trace of "remnant" varices in the form of intervarical nodes where the varices would have been. Varices composed of a series of laminae pressed together; both the ad- and abapertural faces markedly scabrous. Spiral cords crossing the varices as small channels of outfolded laminae, giving the illusion of spinelets, especially at the shoulder. Varices standing free along the siphonal canal as a laminated frill, in the manner of *Naquetia;* with numerous axial growth lamellae between the varices, elaborately crenulated by invisible spiral threads, giving the intervarical areas a cancellate appearance. Aperture elongate-oval; inner lip smooth, only slightly expanded and appressed at the posterior end; inner side of outer lip with seven denticles, those in the center tending to be paired. Siphonal canal medium in length, only indistinctly set off from body whorl. Distal end slightly recurved, with the tips of former canals forming a long curved fasciole.

Dimensions of holotype: height 10.9 mm, diameter 5.5 mm.

Holotype: USNM 294290.

Type locality: TU 546, Ten Mile Creek, about 1¾ miles west of Chipola River (NE ¼ Sec. 12, T1N, R10W), Calhoun County, Florida.

Occurrence: Chipola Formation, late lower Miocene; Florida.

Figured specimens: Fig. 6, USNM 294290 (holotype). Fig. 7, USNM 294291 (paratype); height 9.0 mm, diameter 4.2 mm; locality same as holotype. Other occurrences: TU locality numbers 554, 830, 950, 951.

Discussion: This is the Florida fossil species so like that from the Recent of South Africa, *P. maraisi* Vokes. In addition to size (the photographs of *P. pratulum* are magnified × 5 but those of *P. maraisi* are × 10) the principal difference is in the nature of the protoconch; that of *P. maraisi* is extremely large (for the size of the shell) and of one and one-half bulbous whorls, but that of *P. pratulum* is relatively small, with two and one-half whorls (see photograph of paratype, pl. 1, fig. 7). Both species show nine varices on the early whorls with a decrease on the body whorl. Whether *P. maraisi* would ultimately reduce the number to only six, as does *P. pratulum,* is not known because of the limited amount of material available. The number of intervarical axial growth lines increases in the wider areas but that is

the only change evident as the varices disappear, indicating simply that a longer growth interval takes place before the varix formation rather than the "aborting" of varices that is usual in most muricine groups; for example, *Pterynotus* with a single intervarical node, or species of *Chicoreus* with two.

The name of this species comes from the Latin, *pratulum*, a "little meadow" and is a Latinization of the Anglo-Saxon "shire-leah" (the county assembly ground, or meadow). It is named in honor of the late Shirley (Mrs. R. C.) Hoerle, who over the years, patiently picked out the majority of the specimens in the type lot, including the types.

? PYGMAEPTERYS GERMAINAE
Vokes and D'Attilio, n. sp.
Plate 1, figs. 1-4

Diagnosis: Shell small, with four post-nuclear whorls and a protoconch of approximately one and one-half bulbous whorls, the exact termination being difficult to ascertain among the overlapping varices from the first post-nuclear whorl well onto the protoconch. Spiral ornamentation of two strong cords on the spire; five major spiral cords on the body whorl; three somewhat weaker cords on the siphonal canal. Axial ornamentation of seven varices on each whorl except the last, where there is a tendency to drop one of the varices, leaving a small intervarical node in place of the varix. Intervarical areas covered with elaborately crenulated axial growth lamellae, between and crossing the spiral cords. Each varix forming as a flange, well behind the aperture, with the adapertural face also ornamented by growth lamellae, with small recurved spinelets where the spiral cords cross the varices, that at the shoulder being the longest; a strong adaperatural flexure at the adapical end of each varix, reflecting the posterior expansion of the inner lip. Aperture oval, inner lip in adult specimens with about four denticles at the anterior end and another two at the expanded and appressed posterior end. Outer lip with six strong denticles, corresponding to the area between the spiral cords. Siphonal canal short, broad, recurved at the distal end, terminations of former canals forming a small fasciole. Shell color a light beige, aperture a rich mahogany. Operculum straw-colored, typically muricoid, with a terminal nucleus. Radula muricopsine.

Dimensions of holotype: height 7.3 mm, diameter 4.0 mm.

Holotype: USNM 783319.

Type locality: off Pta. Higüero, (or Jigüero) northwestern Puerto Rico, 90 mts.

Occurrence: Cercado and Gurabo Formations, Miocene; Dominican Republic. Moín Formation, early Pleistocene; Costa Rica. Recent, Caribbean Sea, from Puerto Rico to Panamá, depths from 12 to 90 mts.

Figured specimens: Fig. 1, USNM 783319 (holotype). Fig. 2, USNM 783320 (paratype A); height 7.0 mm, diameter 4.0 mm; off Colon, Panamá, 18 mts. Fig. 3, SDNHM 71305 (paratype B); height 8.6 mm, diameter 4.6 mm; Grenada W. I. (Dieter Cosman Coll.). Fig. 4, USNM 294292 (paratype C); height 6.8 mm, diameter 3.8 mm; locality: TU 1215. Other occurrences: TU locality nos. 953, 1227A, 1230, R-98, R-100, and R-112; off Mayagüez, 45-54 mts, and off Puerto Real, western Puerto Rico, 12 mts (Warmke Collection).

PLATE 1

Figure — Page

1-4 *?Pygmaepterys germainae*, n. sp 50
1. (× 8) USNM 783319 (holotype); height 7.3 mm, diameter 4.0 mm.
Locality: Off Pta. Higüero, Puerto Rico, 90 meters (G. Warmke Coll.).
2. (× 8) USNM 783320 (paratype A); height 7.0 mm, diameter 4.0 mm.
Locality: Off Colon, Panamá, 18 meters.
3. (× 6) SDNHM 71305 (paratype B); height 8.6 mm, diameter 4.6 mm.
Locality: Grenada, W.I. (Dieter Cosman Coll.)
4. (× 8) USNM 294292 (paratype C); height 6.8 mm, diameter 3.8 mm.
Locality: TU 1215, Gurabo Formation, upper Miocene, Dominican Republic.
5. *?Pygmaepterys drezi*, n. sp. 48
USNM 294289 (holotype) (× 4); height 11.8 mm, diameter 7.0 mm.
Locality: TU 546, Chipola Formation, late lower Miocene, Florida.
6, 7 *Pygmaepterys pratulum*, n. sp. (× 5) 49
6. USNM 294290 (holotype); height 10.9 mm, diameter 5.5 mm.
Locality: TU 546, Chipola Formation, late lower Miocene, Florida.
7. USNM 294291 (paratype); height 9.0 mm, diameter 4.2 mm.
Locality: Same as holotype.

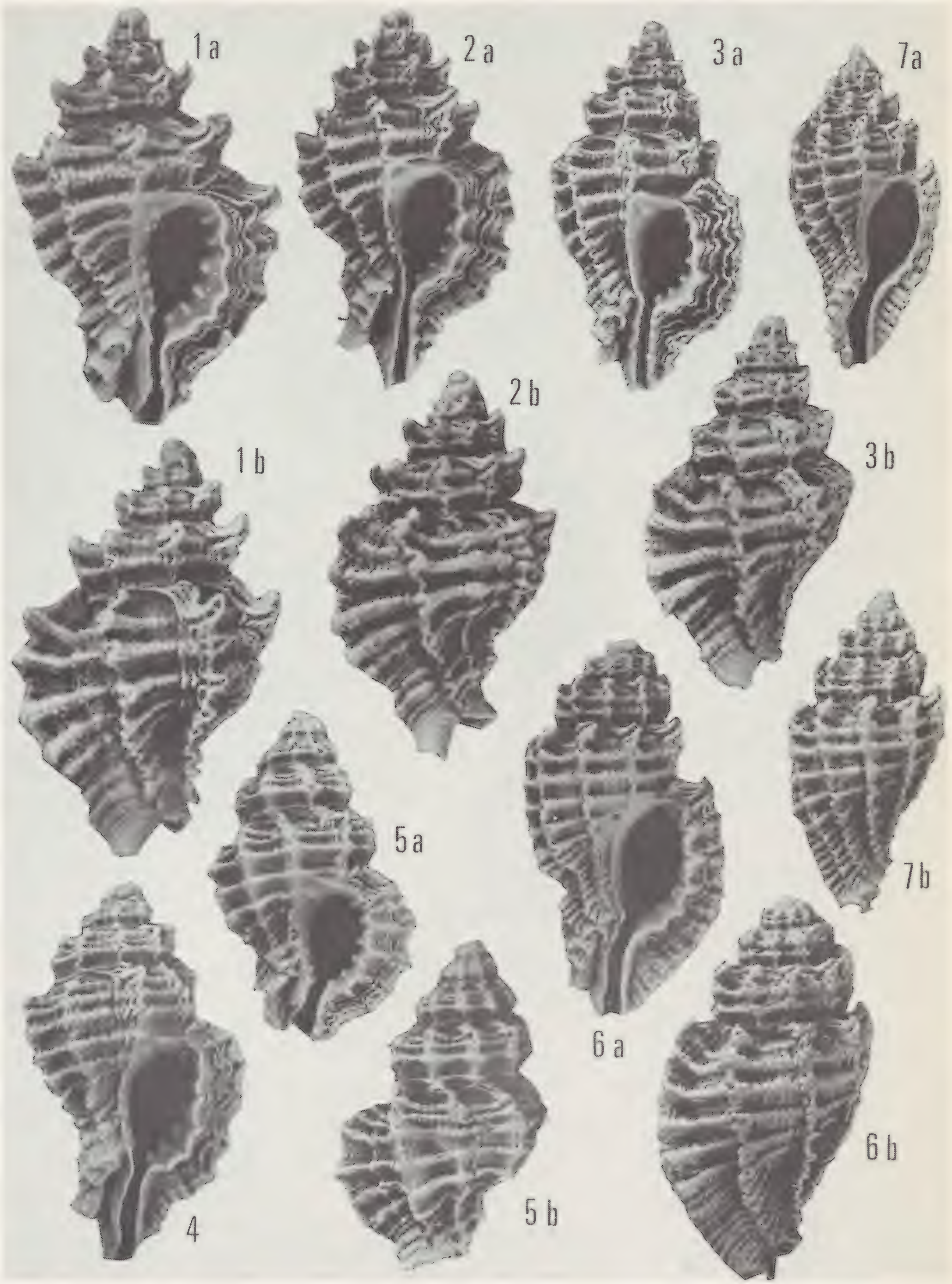


PLATE 1

Discussion: As noted above, this fossil and Recent species is closely related to *P. drezi*, from the lower Miocene Chipola Formation. It differs primarily in being smaller, the largest specimen seen of *P. germainae* is only 9.4 mm in length. Also, there is one less varix per whorl in the modern form, but on the whole the similarity is striking. The aperture, with its labial denticles, is more like the Indo-Pacific *Pterynotus tripterus* (Born, 1778) than any other known form, but this is almost certainly the result of convergence, as *P. tripterus* is the most denticulate of the species of *Pterynotus*, elaborating on a trend that is to be seen to a lesser degree in certain other members of that group. The specimens of *P. germainae* are somewhat variable in the formation of these denticles and more individuals in the type lot lack posterior denticles (for example, paratypes A and C) than have them. As noted above, *P. drezi* has only the anterior nodes, so far as is known.

The Indo-Pacific *P. funafutiensis* (pl. 2, figs. 4, 5) is very close to this species, but the shell is less elaborately ornamented spirally and more ornamented axially. The varices are more expanded and the "spinelets" more pronounced.

This species is named in honor of Germaine (Mrs. H. E.) Warmke, for her work on the Caribbean fauna and for her contribution of much of the type lot, including the holotype.

V. LOCALITY DATA

The following are Tulane University fossil locality numbers:

546. Chipola Fm. Ten Mile Creek, about 1¾ miles west of Chipola River (NE ¼ Sec. 12, T1N, R10W), Calhoun Co., Florida (= USGS 2212, "one mile west of Bailey's Ferry").
554. Chipola Fm. East bank of Chipola River at power line crossing (SW ¼ Sec. 17, T1N, R9W), Calhoun Co., Florida.
830. Chipola Fm. Ten Mile Creek, at power line crossing about one mile west of Chipola River (SE ¼ Sec. 12, T1N, R10W), Calhoun Co., Florida.
950. Chipola Fm. West bank of Chipola River, about 200 feet above Farley Creek (SW ¼ Sec. 20, T1N, R9W), Calhoun Co., Florida.
951. Chipola Fm. Ten Mile Creek, about 1½ miles west of Chipola River (SE ¼ Sec. 12, T1N, R10W), Calhoun Co., Florida.
953. Moín Fm. Type locality, Moín Hill, railroad cut and adjacent ditches on old road to Sandoval, 4.5 km west of Puerto Limón, Costa Rica.
1215. Gurabo Fm. Rio Gurabo, bluffs on both sides, from the bridge to approximately 1 km above the bridge on the Los Quemados-Sabaneta road, Dominican Republic.
1227 A. Gurabo Fm. Arroyo Zalaya, which crosses the road to Janíco from Santiago de los Caballeros, 11 kms south of the bridge of the Rio Yaque del Norte, at Santiago, Dominican Republic. 1227A is a thin lens, resulting from a turbidity flow, which is located on the north side of the arroyo between the "old" bridge (washed out) and the new bridge over the arroyo.

PLATE 2

Figures Page

1. *Pygmaepterys alfredensis* (Bartsch) (× 10) 46
   Natal Museum 5461; height 6.00 mm, diameter 4.2 mm.
   Locality: Port Alfred, South Africa.
2. *Pygmaepterys* cf. *P. alfredensis* (Bartsch) 48
   Houart Coll.; height 16.4 mm, diameter 9.3 mm.
   Locality: Indian Ocean, exact locality unknown.
   (figs. 2a, 2b × 4; 2c × 10)
3. *Pygmaepterys maraisi* (Vokes) (× 10) 47
   Natal Museum A-5048 (holotype); height 5.7 mm, diameter 2.6 mm.
   Locality: Mzamba, South Africa.

4, 5 ?*Pygmaepterys funafutiensis* (Hedley) (× 6) 46

4. From Hedley, 1899; height 9 mm, diameter 5 mm (*fide* Hedley).
   Locality: Funafuti Atoll, Ellice Islands, 40-80 fathoms (73-146 meters).
5. SDNHM 71304; height 9.8 mm, diameter 6.2 mm.
   Locality: Pokai Bay, Oahu, Hawaii, 100 fathoms (183 meters). Salisbury Coll.

PLATE 2

1230. Cercado Fm. East bank of the Rio Caña, at Caimito, just above the bridge on Los Quemados-Sabaneta road, Dominican Republic.

The following are Tulane University Recent locality numbers:

R-98. *Anton Bruun* Cruise 10, dredged in 40 mts northwest of Holandes Cay and east-northeast of Cape San Blas, Panamá; 9°37′ N, 78°50.3′ W.

R-100. *Anton Bruun* Cruise 10, dredged in 50 mts, off Duarte Cays, northwest of Porto Bello, Panamá; 9°36′ N, 79°40′ W.

R-112. Beach drift, Bocas del Toro, Isla de Colon, north coast of Panamá.

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SHIRLEY ELIZABETH HOERLE

The death in 1979 following a long illness, of Shirley E. Hoerle (Mrs. Robert C.) of West Palm Beach, Florida, has deprived the scientific world of one of the more talented students of Tertiary mollusks. Although a self-taught amateur, she was among the most productive in the field. Her unusual ability lead to her appointment as Research Associate at Tulane University and the Paleontological Research Institution, Ithaca, New York.

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E.H.V.

MOLLUSCAN PHYLOGENY*

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U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.

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ABSTRACT

Mollusks are likely descendants of turbellarian-like flatworms and have probably never been segmented. The first mollusks were probably spiculose and lacked a shell; thus, it seems reasonable to regard the Aplacophora as direct descendants of these first mollusks and not as a degenerate group that has lost the shell. A shell probably evolved twice in mollusks, once in the multivalved polyplacophorans and once in the univalved monoplacophorans. The bivalved pelecypods are likely descendants of the univalves. The class Monoplacophora is probably ancestral to the Gastropoda, Cephalopoda, and Rostroconchia. In turn, rostroconchs probably gave rise to the Scaphopoda and Pelecypoda. Possible fossil ancestors of the cephalopods, rostroconchs, pelecypods, and scaphopods are documented and figured.

INTRODUCTION

Because no single soft- or hard-part character, or combination of a relatively few characters, is common to all mollusks, it is not possible to frame a succinct morphological definition of the phylum Mollusca as can be done for such phyla as the Echinodermata and Chordata. Nevertheless, I am convinced that the concept Mollusca is not just a name for a grade of morphological organization achieved by various unrelated invertebrates; on the contrary, I feel that it can be demonstrated that the phylum Mollusca is a phylogenetic entity of great antiquity. Mollusks are unified by morphological gradations between the different forms, by embryological similarities, and by information deduced from fossils of the likely evolutionary history of the various classes assigned to the phylum.

Cuvier (1797) gave the first approximation of what a mollusk is, and natural historians have been refining his concept since that time. For neontologists, this refinement meant elimination of the ascidians, brachiopods, and cirripeds from the concept Mollusca. For paleontologists, it meant adding the monoplacophorans and rostroconchs, and as far as I am concerned it meant eliminating the hyoliths from the phylum (Runnegar *et al.*, 1975; Marek and Yochelson, 1976; and Runnegar, in press a).

Some high level taxa of mollusks still may be unrecognized as such in the fossil record, but in my opinion, *Matthevia* Walcott (Yochelson, 1966; Runnegar *et al.*, 1979) is probably a polyplacophoran; xenoconchs (Shimansky, 1963) may be parts of the internal skeleton of cephalopods; solenoconchs (Starobogatov, 1974) are a heterogeneous assemblage of mollusks and non-mollusks, whose only character in common is an elongate shell (Pojeta and Runnegar, 1979); and too little is known about stenothecoids to determine whether or not they are mollusks (Yochelson, 1968, 1969; Aksarina, 1968; Runnegar and Jell, in press).

Neontologists have long been impressed by morphological gradations between the different forms of living mollusks. In 1883, (p. 634), Lankester proposed the schematic mollusk or archimollusk "in order to exhibit concisely the peculiarities of organization which characterize the Mollusca. . ." This idea has since been elaborated into the con-

*This paper was originally presented as a part of the *Symposium in honor of Katherine Van Winkle Palmer*, see Volume 15, this series.

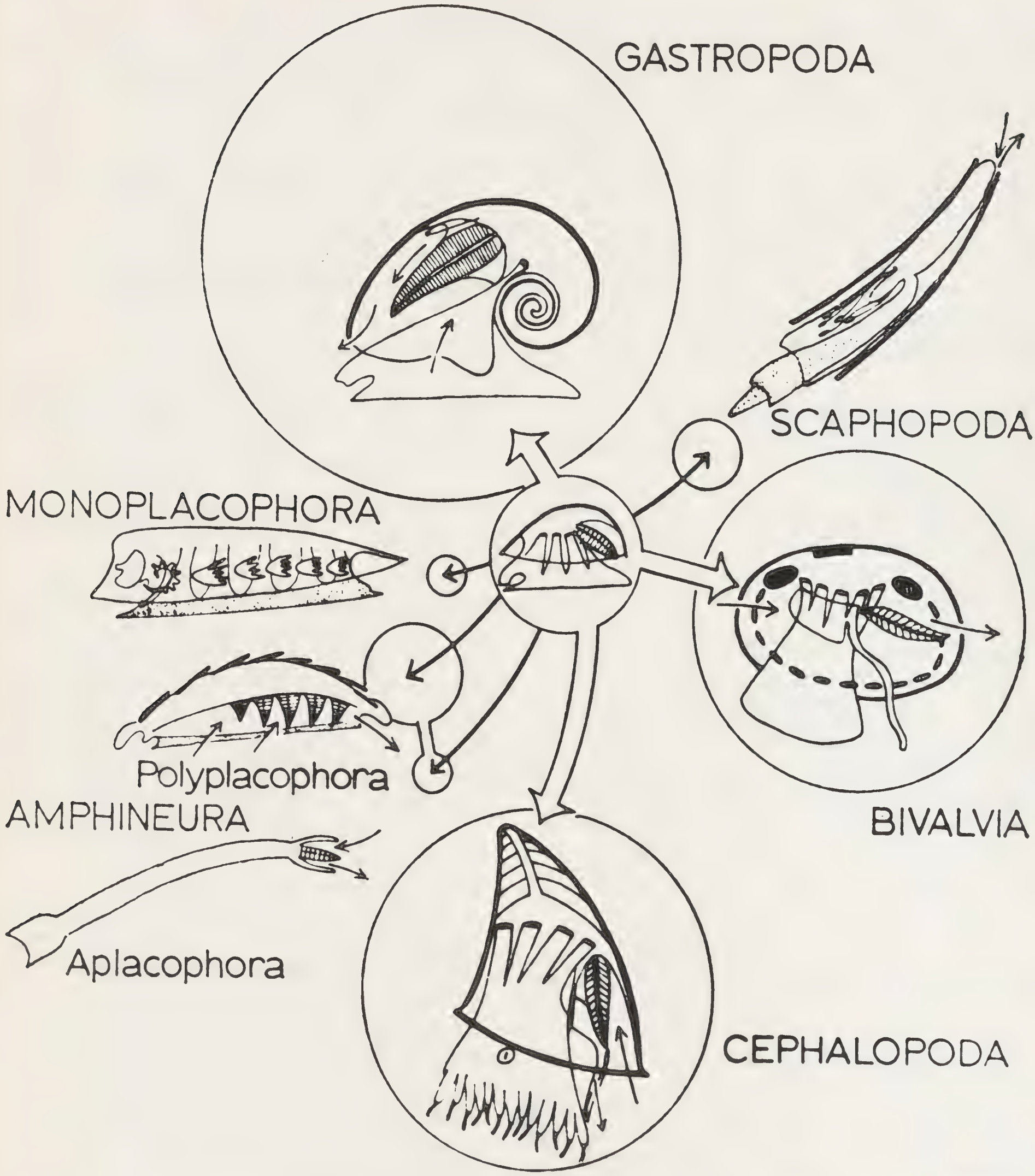


Figure 1. Suggested origins of the various classes of living mollusks from the HAM. Circles suggest the relative size and significance of each class. From Morton, 1967, p. 21, published with the permission of the author.

cept of the hypothetical ancestral mollusk (HAM). The HAM was conceived through the study of the comparative anatomy of living mollusks and has proved to be very useful, partly because assumed knowledge of the common ancestor of mollusks provides a definition of the phylum. The HAM is basically a least common denominator of all structures regarded as primitive in the various classes of extant shelled mollusks.

Zoologists ordinarily consider each molluscan class to have evolved independently from the HAM (Figure 1). This means that the archetype must have existed from the late Precambrian to at least the late Middle Ordovician, periodically taking on a new shell form to become a new class of mollusks (Yochelson, 1978b). This evolutionary strategy seems most unlikely, and the idea flies in the face of principles of the evolution of

higher taxa as determined from the study of fossil vertebrates. Almost all illustrations of the HAM show it as having a univalved shell. Such a condition requires that aplacophorans be considered degenerate mollusks, which have lost their shell. It seems more reasonable to follow Scheltema's (1978) view that characteristic molluscan structures evolved in the aplacophorans independently of a shell. Accordingly, the relatively simple morphology and anatomy of aplacophorans may be considered primitive rather than degenerate, and an alternative picture of molluscan higher level phylogeny emerges.

A recent explanation of what the HAM looked like (Figure 2) was given by Yonge (1976). His figure shows an animal that has a univalved limpet-shaped shell, multiple pedal retractor muscles, with the mouth and anus widely separated and at opposite ends of the shell. Such a creation is effectively a monoplacophoran, and if it were found as a fossil, it would be so classified.

Several zoologists have advised caution about the use of the HAM as central to an understanding of molluscan evolution. Stasek (1972) noted that at best the HAM is only a convenient tool for teaching the comparative morphology of mollusks. Morton (1967, p. 14) pointed out the danger of using the HAM to define Mollusca as well as the problems raised by thinking of the HAM as a reasonable reconstruction of the ancestral mollusk when he wrote: "The danger is that in mixing geneological ideas with morphology our archetype may become like an heraldic animal — a lowest common multiple of incompatible organs." Although it was formerly a useful concept, it now seems likely that the HAM is no longer a necessary device for understanding molluscan evolution.

Another approach to understanding molluscan evolution is to consider how one class of mollusks may have arisen from a preexisting class. This approach concentrates on the study of Cambrian and Ordovician mollusks because all classes were in existence by the end of the Middle Ordovician (Pojeta and Runnegar, 1976, 1979; Runnegar *et al.*, 1979), and it requires a search for forms that are intermediate in morphology between recognized molluscan classes. The

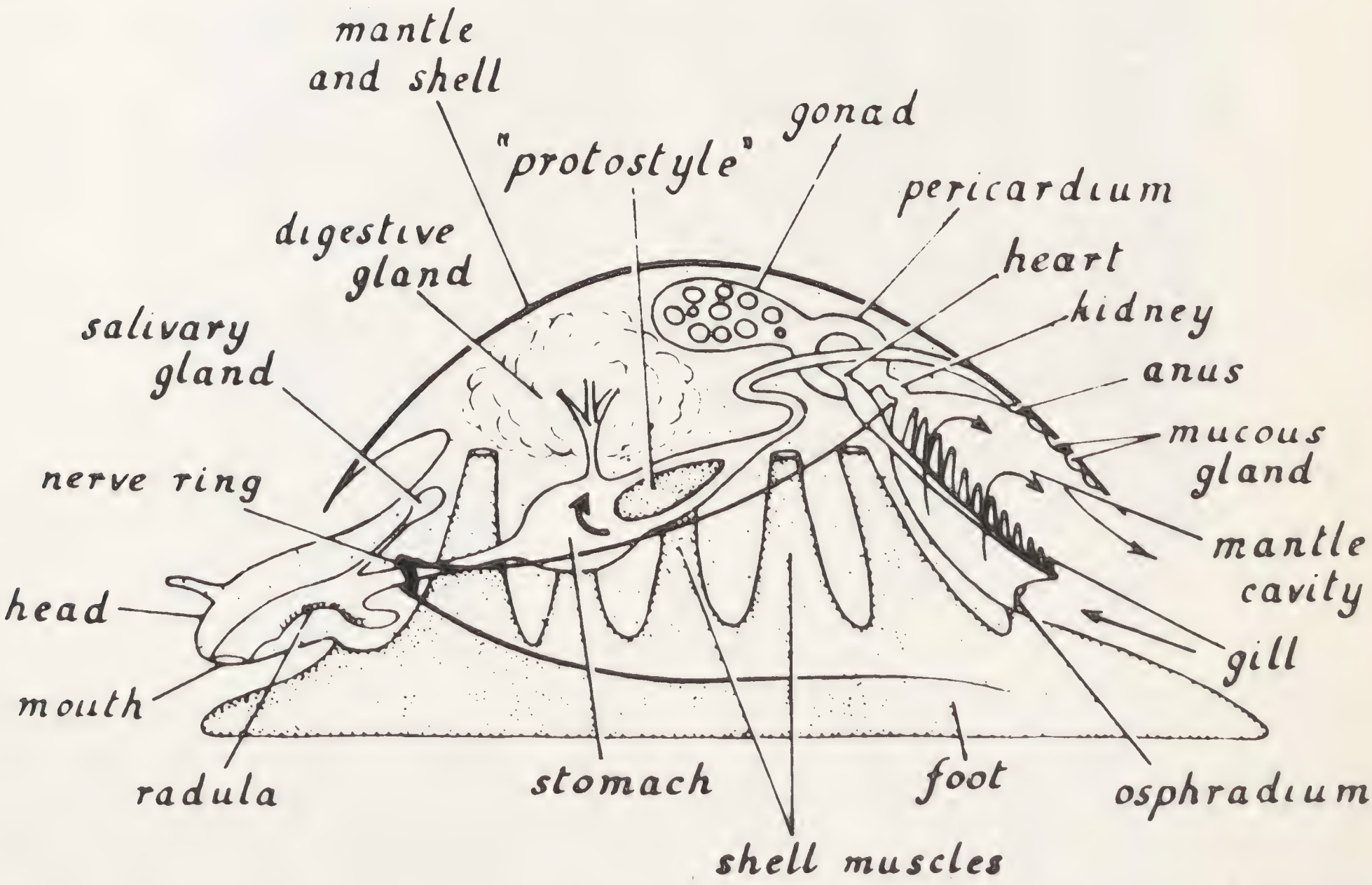


Figure 2. Reconstruction of the HAM. From C. M. Yonge, 1976, The nature of mollusks, *in* C. M. Yonge and T. E. Thompson, Living marine mollusks; London, William Collins Sons and Co., Ltd., p. 25, published with the permission of the author.

finding of fossils that are reasonably placed stratigraphically and morphologically intermediate between classes has proved to be remarkably successful in developing an understanding of the origin of higher level groups of vertebrates. We have morphological intermediates between several classes of mollusks that I believe are as significant for understanding molluscan phylogeny as *Archaeopteryx* and *Eusthenopteron* are for understanding the pathways of vertebrate phylogeny. It seems unlikely that molluscan ". . . classes begin abruptly by major mutations of larval forms which opened new environmental niches" as suggested by Yochelson (1978a, p. 10; 1978b, p. 166, 186; 1979, p. 323). Implicit in this point of view is that changes that take place in larvae cannot be preserved in the fossil record. Secretion of a skeleton in mollusks ordinarily begins early in ontogeny; even if all class level differences were due to neotony, when the zygotes formed by fusion of the gametes contain the hereditary information necessary to produce an individual having a skeleton, the changes could be preserved in the fossil record.

ORIGIN OF THE MOLLUSCA

At present, it seems likely that the Precambrian ancestor of mollusks was a small ciliated wormlike organism without a coelom. This organism showed pseudometamerism in having a serial repetition of some organ systems along the length of the body, but it was without transverse septa subdividing the body into segments and lacked numerical correlation of the various organ systems. Thus, the number of diges-

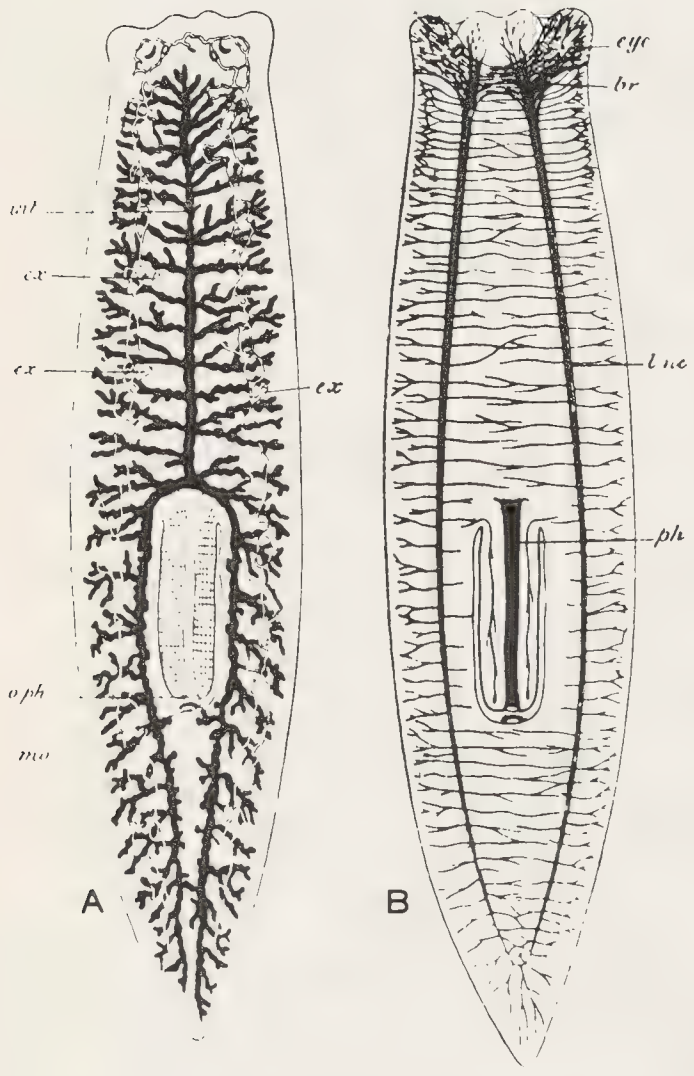


Figure 3. Pseudosegmentation in the turbellarian *Planaria*. (A) Digestive (black) and excretory (open) systems. (B) Nervous system. *ex*, openings of excretory system; *int*, intestine; *mo*, mouth; *o. ph*, opening of pharynx; *br*, brain; *eye*, eye; *l. ne*, longitudinal nerve; *ph*, pharynx. From T. J. Parker, and W. A. Haswell, 1961, A Textbook of Zoology, p. 220, published by permission of Macmillan, London and Basingstoke.

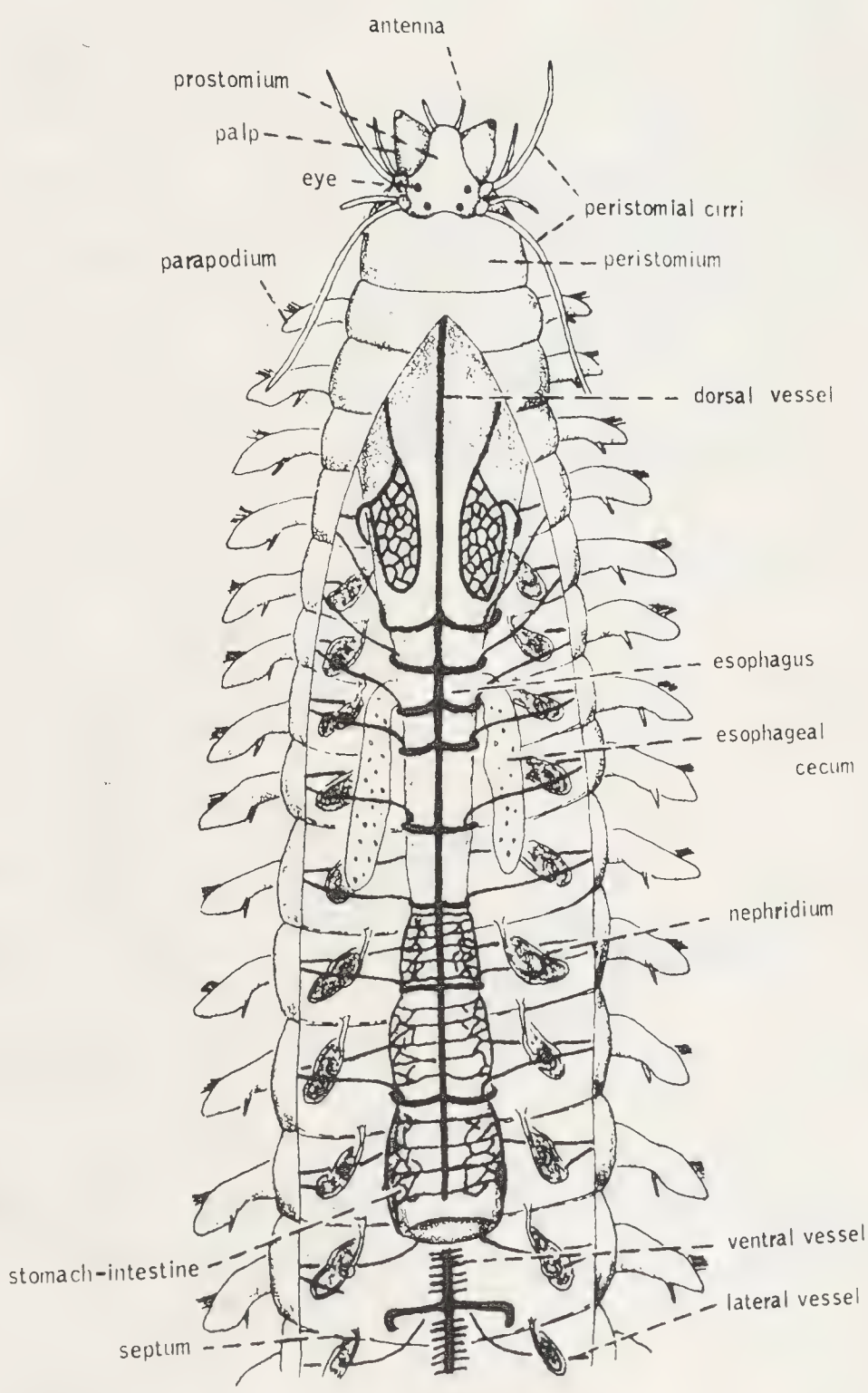


Figure 4. Segmentation in the annelid *Nereis*. After F. A. Brown, Jr., 1950, Selected invertebrate types, p. 273, New York, John Wiley and Sons, Inc., copyright 1950, as modified by Barnes, 1963, Invertebrate zoology, p. 173, Philadelphia, W. B. Saunders Co. Published with the permission of John Wiley and Sons, Inc., and W. B. Saunders Co.

tive diverticula did not correspond to the number of lateral nerve branches or to the number of protonephridia. I believe that this ancestor of mollusks was probably most like living turbellarian flatworms (Figure 3).

It now seems unlikely that mollusks ever possessed metamerism in the sense that this feature is seen in annelid worms; these worms have a body composed of repeated segments separated one from another by septa, several of the organ systems being numerically correlated and occurring in each segment. The embryological and larval similarities between mollusks and annelids probably reflect their origins in a common ancestor, which was a pseudosegmented turbellarian-like flatworm. Annelids developed segmentation (Figure 4),

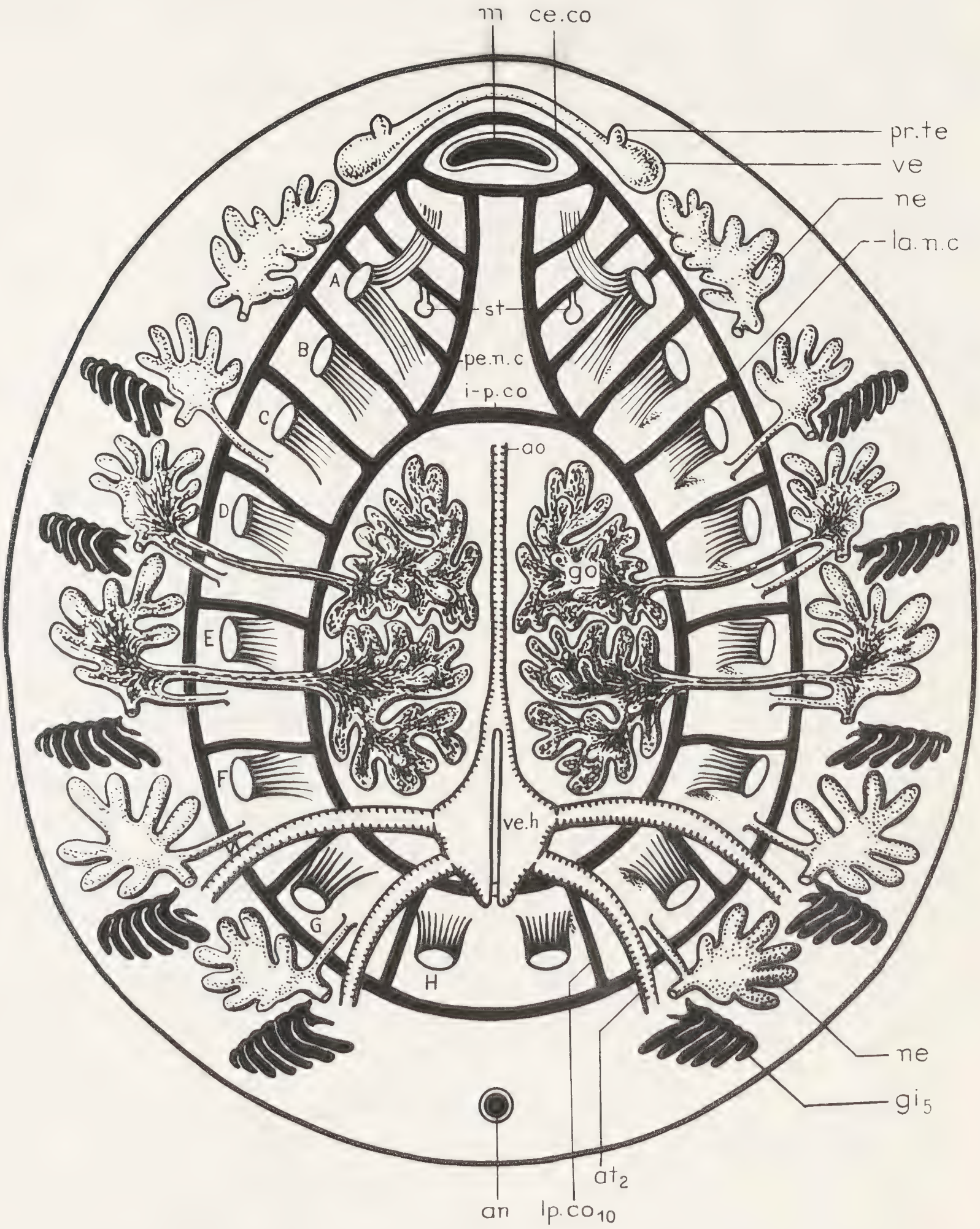


Figure 5. Pseudosegmentation in the monoplacophoran *Neopilina*. *A-H*, pedal retractors; *an*, anus; *ao*, aorta; at_2, second atrium of heart; *ce. co*, cerebral commissure; gi_5, fifth gill; *go*, gonads; i-p. co, interpedal commissure; *la. n. c*, lateral nerve cord; *lp.* co_{10}, tenth lateropedal connective; *m*, mouth; *ne*, nephridia; *pe. n. c*, pedal nerve cord; *pr. te*, preoral tentacle; *st*, statocyst; *ve*, velum; *ve. h*, ventricle. From Henning Lemche, and K. G. Wingstrand, 1959, The anatomy of *Neopilina galatheae* Lemche, 1957: Galathea Rept., v. 3, plate 54, published with the permission of K. G. Wingstrand and Torben Wolft, editor of Galathea Reports.

whereas in mollusks numerical correlation of the organ systems did not evolve, although some mollusks retained well-defined pseudosegmentation (Figure 5).

Stasek (1972) explained how a turbellarian-like animal could evolve into a mollusk. He pointed out that most of the features that distinguish mollusks could have arisen as the result of a single evolutionary accomplishment, which was the secretion of a mucoid cuticle over the dorsal body wall surface. The dorsal body-wall surface secreting the cuticle could be considered the primitive mantle. Secretion of aragonitic spicules embedded in a cuticle takes place in the primitive aplacophoran and polyplacophoran mollusks (Figure 6), and similar aragonitic spicules (Figure 7) occur in the body wall of some living turbellarian flatworms (Rieger and Sterrer, 1975). It seems likely that the primitive molluscan skeleton was spiculose and not composed of layered calcium carbonate. Allison (1975) described a possible turbellarian flatworm from what she considered to be Precambrian rocks in Alaska, but Cloud *et al.* (1976) suggested that her specimen was a hexactinellid sponge spicule.

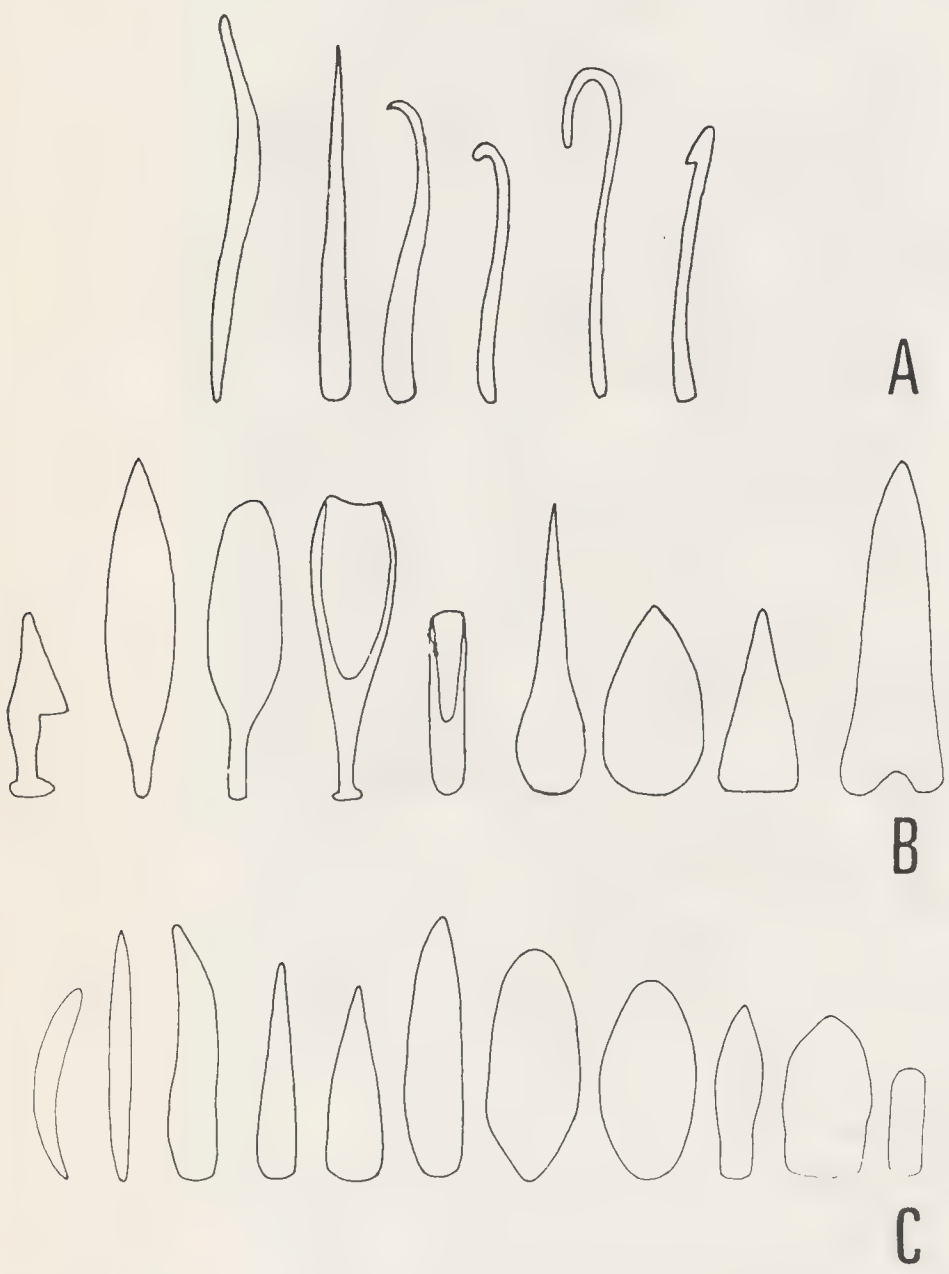


Figure 6. Outline drawings of spicules of some living mollusks. Shapes in rows A and B are found in aplacophorans. Shapes in row C occur in polyplacophorans. Spicules in these classes are generally small to microscopic, but reach a length of 4 mm in aplacophorans and 10 mm in polyplacophorans (Hyman, 1967, p. 17, 79).

Cuticular spicules may have been cemented together subsequently by the outer layer of the primitive ostracum as in some pelecypods (Aller, 1974; Carter and Aller, 1975), or the ostracum may have been secreted entirely below the spicule-bearing cuticle (Figure 8). Whatever way the layered calcium carbonate shell was formed, it raised the spiculose cuticle above the dorsal body wall forming the periostracum. Of necessity, the periostracum has since remained thin because it is in contact with the secretory mantle only along the shell edge in the periostracal groove. The tendency has been for mollusks to lose the spicular skeleton, but it is fully retained in aplacophorans, partially retained in polyplacophorans, and is found in a few pelecypods (Figure 8).

At the stage in the evolution of mollusks when the mantle and the shell were present and when these became extended as eaves beyond the edge of the body, a mantle cavity was formed (Figure 9), in which gills could develop. The eaves also separated the body into a ventral foot and a dorsal visceral mass. Gills would have to form when the shell evolved because the latter process would decrease the surface area of the body wall available for epithelial respiration. When gills had evolved, body size could be increased. Most Early and Middle Cambrian mollusks are small; major size increases in all shelled classes took place in the Late Cambrian or Ordovician.

This much of the molluscan story is deduced primarily from living mollusks, and much of it is based on Stasek's (1972) work. However, from the earliest Cambrian (Tommotian) onward, shell-bearing mollusks are known in the fossil record (Rozanov *et al.*, 1969; Matthews and Missarzhevsky, 1975; Qian *et al.*, 1979; and Yü, 1979). In my opinion, these fossils, as well as Middle and Late Cambrian mollusks, tell us much about the probable origins of cephalopods, pelecypods, rostroconchs, and scaphopods and allow us to make reasonable deductions about the origins of polyplacophorans, gastropods, and monoplacophorans. The conclusions based on fossils are discussed next in the systematic section.

CLASSIFICATION OF THE MOLLUSCA USED HEREIN

Phylum MOLLUSCA Cuvier, 1797

Subphylum AMPHINEURA von Ihering, 1876
- Class APLACOPHORA von Ihering, 1876
- Class POLYPLACOPHORA de Blainville, 1816

Subphylum CYRTOSOMA Runnegar and Pojeta, 1974
- Class MONOPLACOPHORA Knight, 1952
- Class GASTROPODA Cuvier, 1797
- Class CEPHALOPODA Cuvier, 1797

Subphylum DIASOMA Runnegar and Pojeta, 1974
- Class ROSTROCONCHIA Pojeta, Runnegar, Morris, and Newell 1972
- Class PELECYPODA Goldfuss, 1820
- Class SCAPHOPODA Bronn, 1862

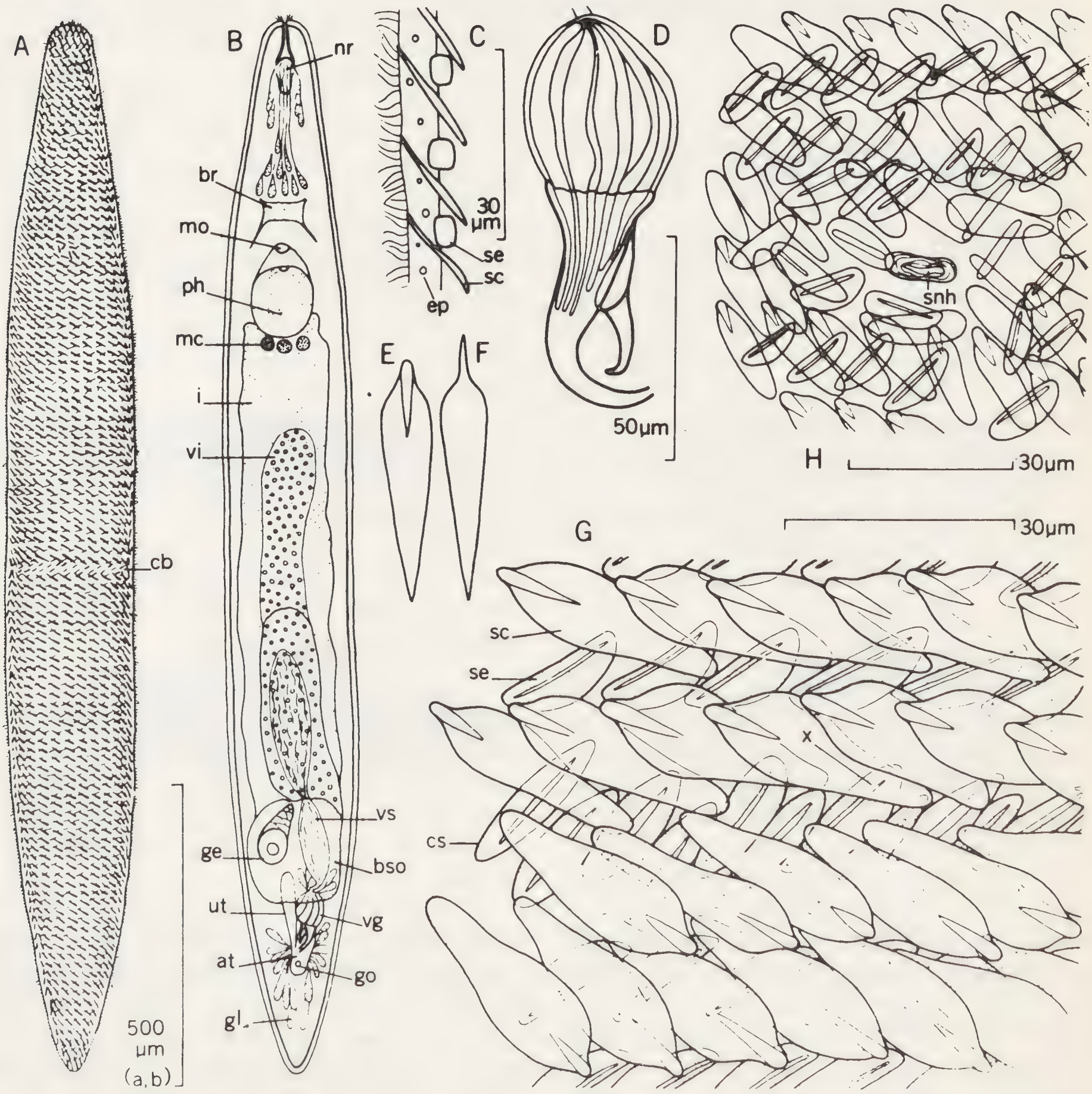


Figure 7. Spicules in the living turbellarian *Florianella bipolaris* Rieger and Sterrer. From R. M. Rieger, and Wolfgang Sterrer, 1975, Sonderbruck aus Z. f. zool. Systematik u. Evolutionforschung, v. 13, no. 3, p. 209. Published with the permission of the Publishing House of Paul Parey, Hamburg 1, Spitalerstrasse 12, West Germany, which owns the copyright.

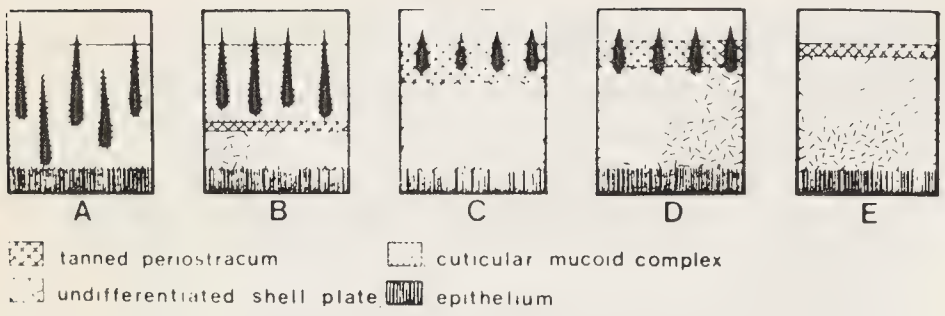


Figure 8. Organization of cuticle and shell in some living mollusks. (A) Aplacophora; (B) Polyplacophora; (C) Some Pelecypoda; (D) Some Pelecypoda; (E) Most Pelecypoda. Black teardrop-shaped objects are spicules. From J. G. Carter, and R. C. Aller, 1975, Lethaia, v. 8, p. 318, published with the permission of the senior author and the editors of Lethaia.

ORIGIN AND EVOLUTION OF THE HIGHER TAXA OF MOLLUSKS

Subphylum AMPHINEURA

The subphylum Amphineura contains those mollusks in which the primitive spicular skeleton embedded in a cuticle has remained prominent, and is composed of the classes Aplacophora and Polyplacophora. In addition to having spicules embedded in a cuticle as a prominent part of the exoskeleton, these classes show anatomical similarities (Hyman, 1967) and both lack a veliger larval stage in their ontogeny.

Class Aplacophora

Aplacophorans (Figure 10) have a radula, a style sac, a mantle cavity, and various other soft-part features that indicate that they are mollusks (Scheltema, 1978). They have the simplest morphology of any living mollusk, and if one does not use the HAM concept, they can be considered a primitive group rather than a degenerate one. Scheltema (1978), Salvini-Plawen (1975), and Beedham and Trueman (1968) regarded aplacophorans as primitive mollusks. Scheltema (1978, p. 108) noted that they had evolved several molluscan structures independent of a shell. Salvini-Plawen (1969) preferred to divide the Aplacophora into two taxa of class rank.

The first mollusks probably were similar to aplacophorans in having a spiculose cuticle prior to the evolution of the shell. Aplacophorans can be regarded as the living descendants of these early mollusks, which were intermediate between turbellarian-like flatworms and shelled mollusks. The aplacophorans are the only surviving group of mollusks whose ancestors never secreted a shell and thus give insight into what the ancestral mollusk may have looked like — a vermiform spiculose animal with a mucoid cuticle. Beedham and Trueman (1968) indicated that the aplacophorans lack a shell because the cuticle is not hardened by quinone-tanned protein and thus cannot act as a semiconducting membrane for the deposition of calcium salts in crystalline layers.

Unfortunately, aplacophorans have no unequivocal fossil record. Nierstrasz and Stork (1940, pl. 3, fig. 55; Figure 11A herein) figured some spicules of the living species *Uncimenia neapolitana* Nierstrasz, which have a cane shape. More or less similar cane-shaped spicules are known from Ordovician rocks (Figure 11B); these have been placed in the genus *Ptiloncodus* Harris and to date have been found only in phosphatic residues. The spicules of apalcophorans have a variety of characteristic shapes (Figure 6A-B) and could be preserved as fossils.

I propose that there are three descendant groups from the spiculose ancestral mollusk: (1) the aplacophorans themselves, (2) the polyplacophorans, and (3) the monoplacophorans. These three groups have had long separate histories and are related to one another only at the very base of the molluscan stem.

Class Polyplacophora

The idea that polyplacophorans are an early offshoot in molluscan history and that they have an origin separate from that of the rest of the shell-bearing mollusks is supported by several lines of evidence, including the following:

(1) Polyplacophorans have a multivalved shell (Figure 12). All other shelled mollusks can be traced back to a primitive univalved condition, but there is no known paleontological evidence that polyplacophorans ever had a single valved shelled ancestor. Embryological evidence suggests that the original number of valves may have been seven (Hyman, 1967), and one species from the Ordovician, *Septemchiton vermiformis* (Bergenhayn, 1955) has only seven valves. The valves of chitons may have originated as enlarged spicules (Runnegar *et al.*, 1979)

or spicules may have been cemented together to form the valves. Haas and Kriesten (1977) noted that the long girdle spines of the living chiton *Acanthopleura granulata* (Gmelin) develop from a single cell which divides to form a "regular lime secreting epithelium" (p. 11). This process differs from that in aplacophorans, where each body wall spicule is produced by a single cell. In polyplacophorans, a number of cells cooperate to produce spicules, and such cytological integration in the mantle produces the valves of polyplacophorans and the shell in other shell-bearing mollusks.

(2) Stasek (1972) noted that the polyplacophoran shell layer known as the articula-

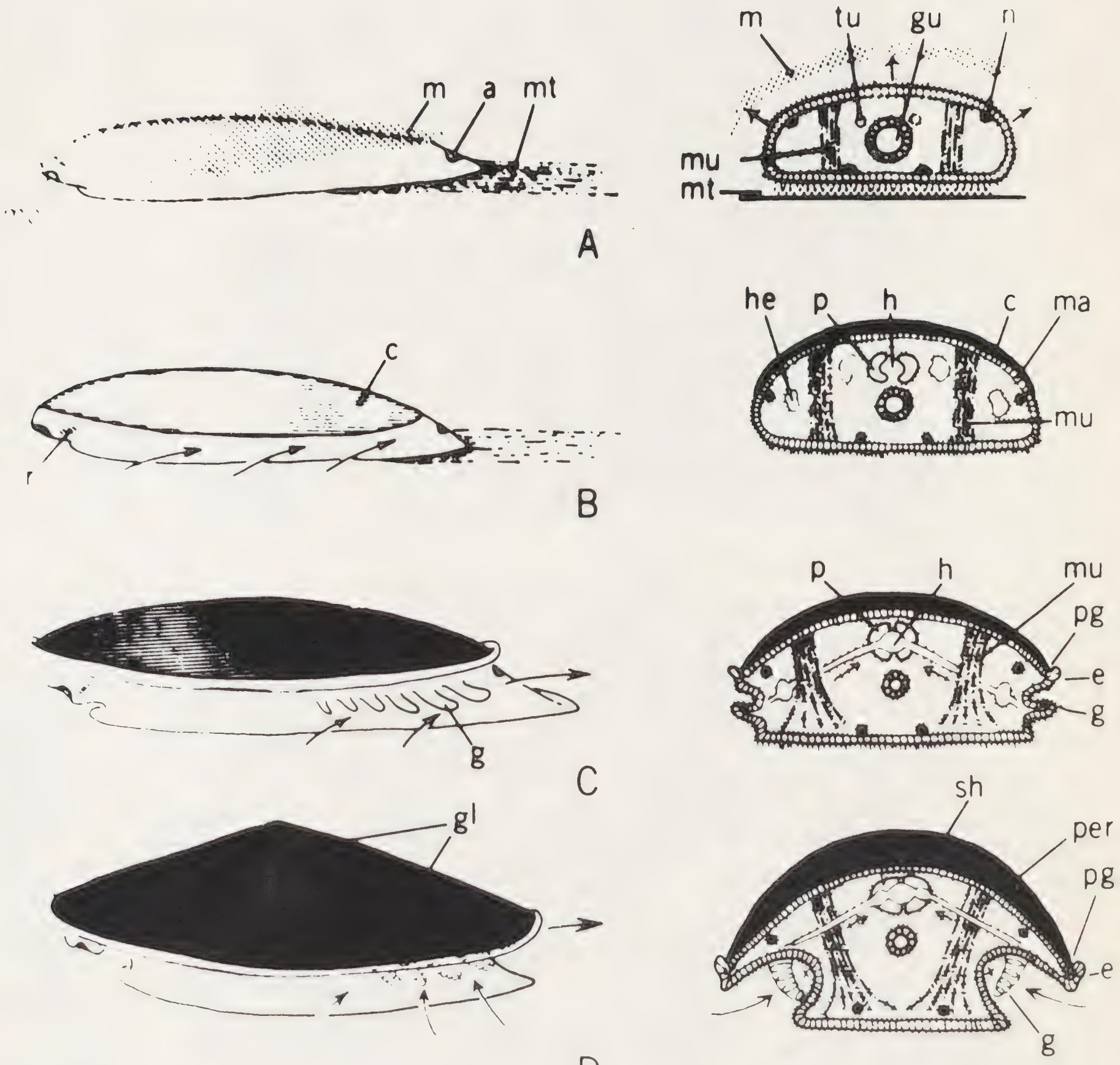


Figure 9. Four stages in the establishment of the molluscan framework from a turbellariform organism, all shown in lateral and cross-sectional views. (A) Proposed ancestral form with a complete gut and ability to secrete mucous as a protective measure and as a locomotory track. (B) Transitional turbellariform stage with radula and cuticle. (C) Transitional molluscan stage with gills contained in an incipient mantle cavity underlying eaves of the mantle. (D) Advanced molluscan stage with calcified cuticle and folded gills. *a*, anus; *c*, cuticle; *e*, eaves of mantle; *g*, gills; *gl*, growth lines; *gu*, gut; *h*, heart; *he*, hemocoelic sinuses; *m*, mucous covering; *ma*, mantle; *mo*, mouth; *mt*, mucous track; *mu*, dorsoventral muscles; *n*, longitudinal nerve cords; *p*, pericardium; *pg*, periostracal groove; *r*, radula; *sh*, shell; *tu*, gonoducal tubercles. From C. R. Stasek, 1972, The molluscan framework, *in* v. 7, Mollusca, Marcel Florkin, and B. T. Scheer, eds. Chemical Zoology; New York, Academic Press, p. 6. Published with the permission of the author and the publisher.

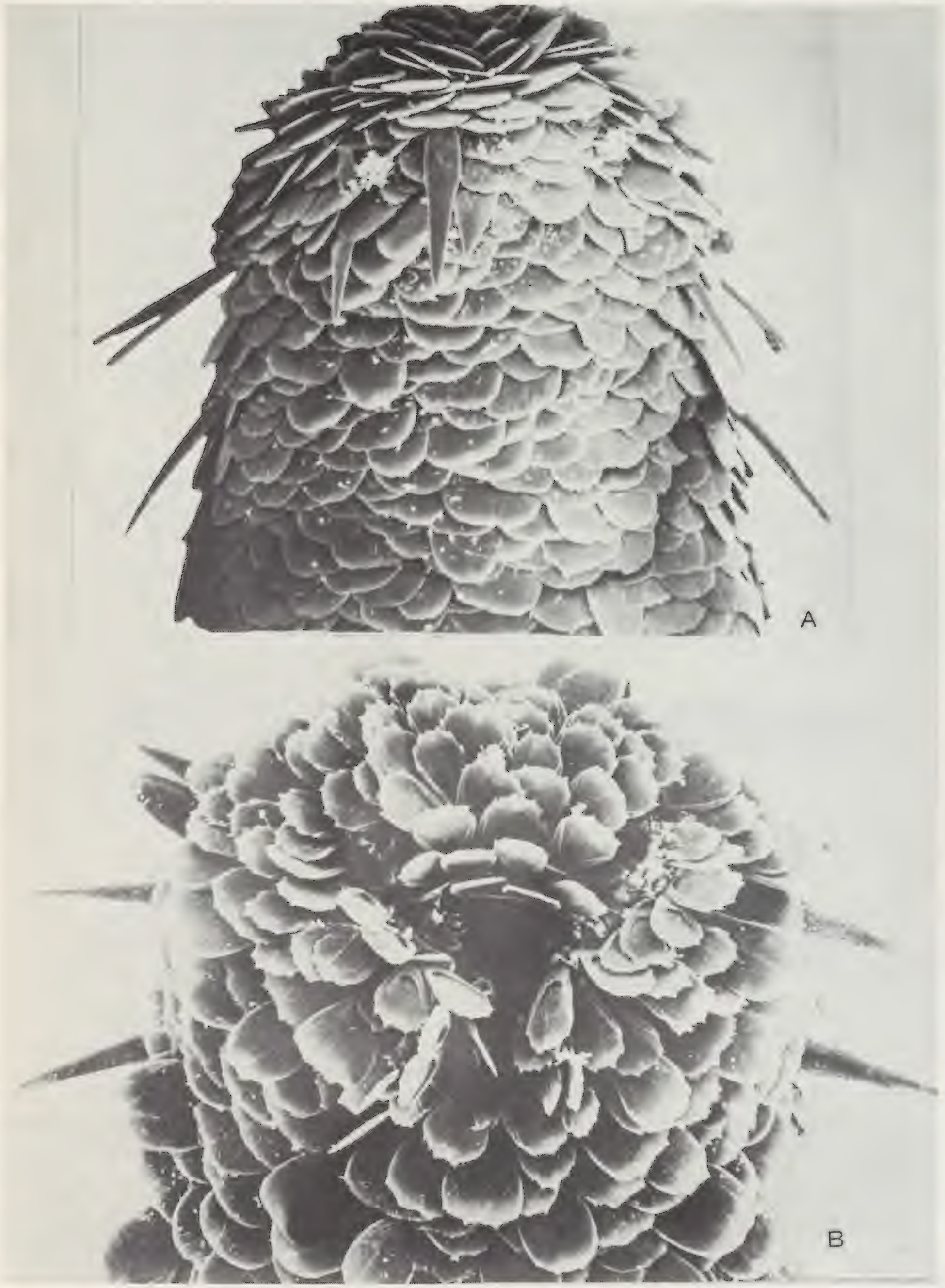


Figure 10. Unnamed interstitial aplacophoran from Friday Harbor, San Juan Island, Washington. (A) Dorsal view of head, ×700. (B) Ventral view of head, ×750. Photographs courtesy of M. P. Morse, Northeastern University. Museum of Comparative Zoology (MCZ), Harvard University 92177, 72977.

mentum, which is present in advanced polyplacophorans and forms the insertion plates and anterior prongs, evolved after the chitons were already a differentiated molluscan lineage. I also have observed that the Cambrian and Ordovician chitons *Matthevia* Walcott and *Chelodes* Davidson and King lack the articulamentum. This indicates that the articulamentum is not homologous with the inner shell layer of the shells of other mollusks. The vesicular structure of the shell of the Late Cambrian chiton *Matthevia* (Figure 13) is very different from the layered calcium carbonate typical of the shell structure of other shell-bearing mollusks. Beedham and Trueman (1967) suggested homologies between the shell layers of polyplacophorans and other shell-bearing mollusks, but in the light of the paleontological evidence their suggested homologies should be reappraised.

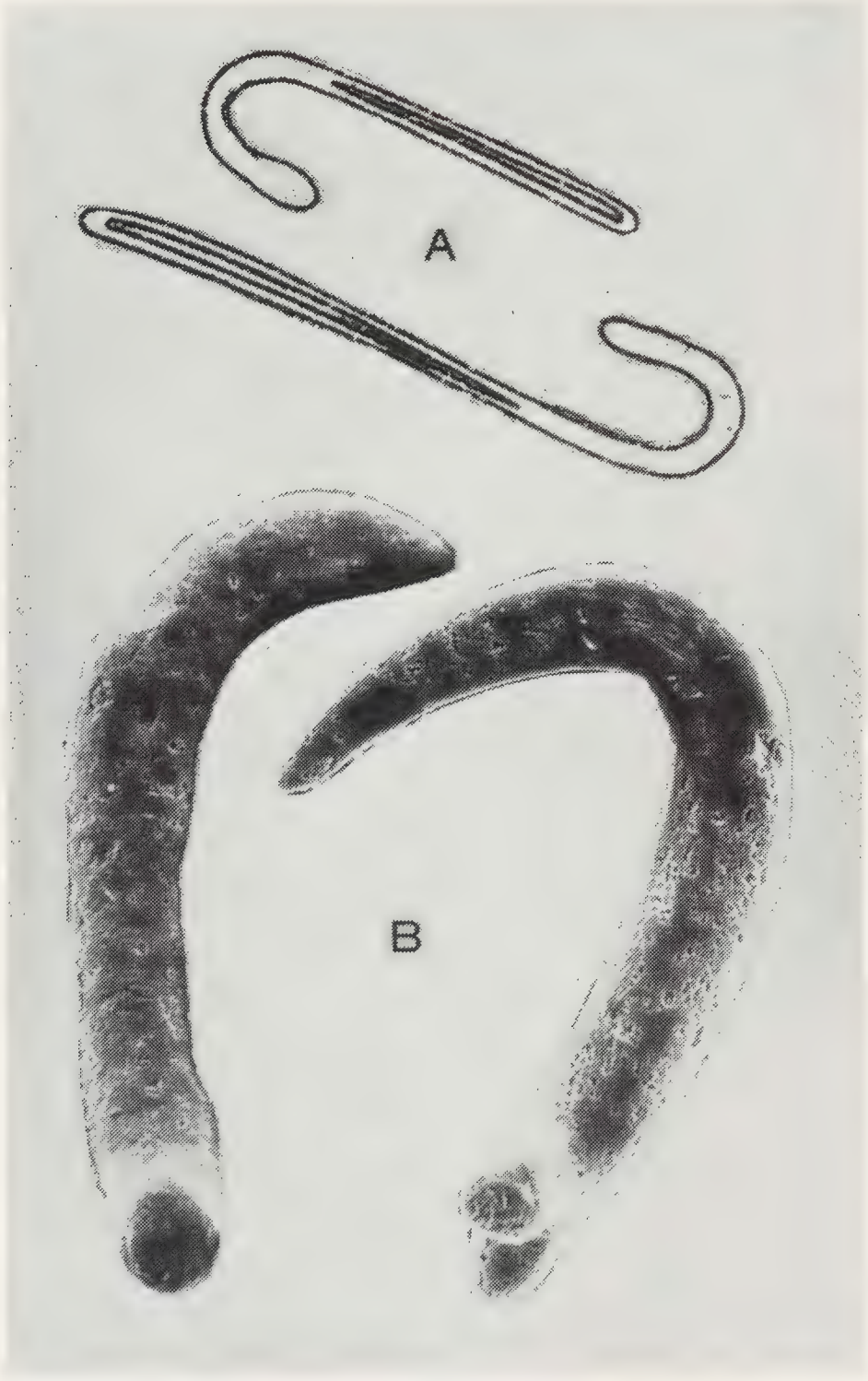


Figure 11. (A) Cane-shaped spicules of the aplacophoran *Uncimenia neapolitana* Nierstrasz, magnification unknown, from Nierstrasz and Stork, 1940, pl. 3, fig. 55. (B) Cane-shaped bodies named *Ptiloncodus simplex* R. W. Harris, from Middle Ordovician (Whiterockian) of Nevada, ×125. Specimens kindly provided by A. G. Harris, U. S. Geological Survey. U. S. National Museum of Natural History (USNM) 298722, 298723.

(3) Chitons have an inner and outer cuticle. The outer cuticle is on the girdle, and embedded in it are spicules. The outer cuticle contains mucoid material and is similar in many respects to the cuticle of aplacophorans. The inner cuticle may act like a semiconducting membrane in the deposition of the shell valves (Beedham and Trueman, 1967, 1968).

(4) There is still debate about how to compare the mantle margin of chitons with that of other mollusks (Beedham and Trueman, 1967).

(5) The shell surface of such Late Cambrian chitons as *Matthevia* and *Preacanthochiton* Bergenhayn (Figure 14) is covered with tubercles or granules; this feature suggests that the valves may have originally been secreted as spicules, which were later cemented together.

Thus, it seems likely that chitons evolved from a spiculose aplacophoran-like ancestor. It is only at this stage that they have a common ancestry with the Monoplacophora; monoplacophorans appear to be the likely ancestors of all other shell-bearing mollusks.

The Late Cambrian chiton *Matthevia* Walcott has been the subject of controversy in recent years because this genus was made the sole representative of a supposed extinct class of mollusks (Yochelson, 1966, 1978b). This point of view now seems unlikely (Runnegar *et al.*, 1979).

The reconstruction of *Matthevia* that I favor is shown in Figure 15. It seems likely that *Matthevia* was a high subtidal to intertidal scraper of stromatolites, as it is found mainly in stromatolitic carbonate rocks sometimes associated with high-relief domal stromatolites (Runnegar *et al.*, 1979).

The reconstruction of *Matthevia* proposed by Yochelson (1966) (Figure 16 herein) seems unlikely for the following reasons:

(1) The type suite of the type species of the genus, *M. variabilis* Walcott, contains valves having three different shapes, but all have the same ornament (Runnegar *et al.*, 1979); all three types should be incorporated in a reconstruction, but only two types were available to Yochelson in 1966.

(2) In Yochelson's preferred reconstruction (Figure 16 herein), there is not only a space between the valves for a foot to protrude ventrally, but also a space between the valves dorsally (Figure 17C). Such a dorsal opening would not have allowed the shell to protect the animal.

(3) The embayed side of *Matthevia* valves has one or two deep holes, which are interpreted as muscle insertions (Figure 17A-B). In Yochelson's preferred reconstruction (Figure 16), there seems to be no way for the muscles to function. If the muscles extended in a straight line from the insertion to the visceral hump, once they contracted there is no obvious antagonist, such as another muscle or a ligament, to stretch them out again; although they could conceivably be stretched again in some hydrostatic manner. If the muscles extended from the insertions into the foot they would have to go through a high-angle bend, and in most animals, muscles do not undergo such a sharp bend. However, more important than the high-angle bend is that once muscles in this position contracted, the apices of

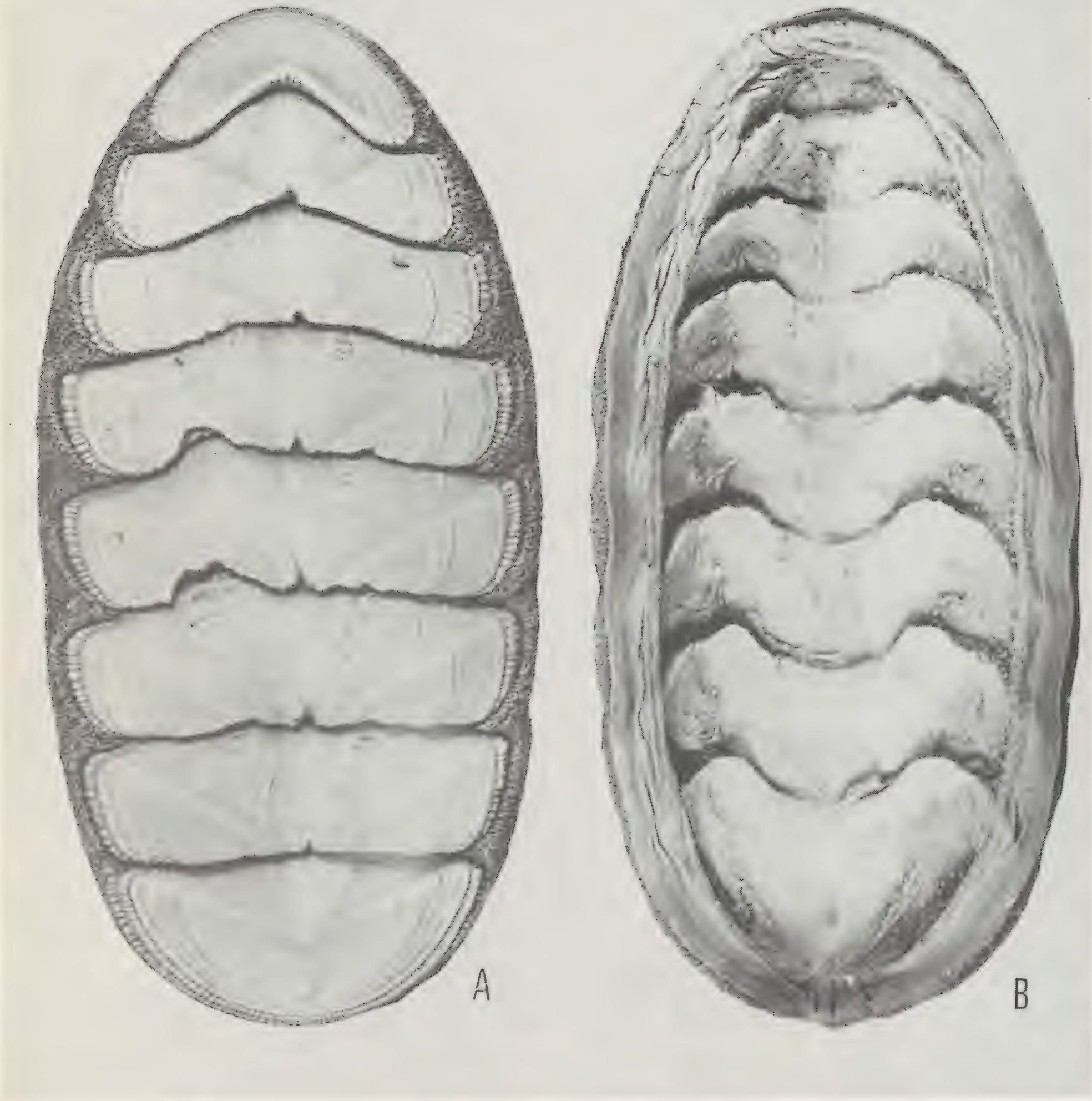


Figure 12. Dorsal exterior (A) and interior (B) views of the living polyplacophoran *Stenoplax conspicua* Carpenter, ×1.5, USNM (Division of mollusks) 172894.

the valves would turn upward and expose the ventral soft parts.

(4) The shell shapes of the terminal and intermediate valves of the undoubted Ordovician chiton *Chelodes* closely resemble the shapes of the intermediate and posterior valves of *Matthevia* in the interpretation of Runnegar *et al.*, (1979).

(5) Yochelson (1978b, p. 175) made the comment ". . . no polyplacophoran has more than one muscle insertion per plate . . ." This observation is contradicted by the known musculature of living polyplacophorans (Figure 18 herein, and Sampson, 1895).

(6) Yochelson's (1966, p. B7) concern about the weight of *Matthevia* valves is obviated by their vesicular shell microstructure (Figure 13), which would have considerably reduced the weight of the valves; more than two could have been carried on the dorsal side.

CONCHIFERA

It is in the remaining six classes of mollusks that I see molluscan missing links equivalent in importance to *Archaeopteryx* and *Eusthenopteron* in determining lines of descent. Ultimately, these six classes of mollusks descended from the Monoplacophora, and they are sometimes united in the subphylum Conchifera (Salvini-Plawen, 1969, 1975). I prefer to place the six classes in two subphyla, the Cyrtosoma and the Diasoma (Runnegar and Pojeta, 1974; Pojeta and Runnegar, 1976).

The Cyrtosoma includes the classes Monoplacophora, Gastropoda, and Cephalopoda, or the ancestral conchiferan radical

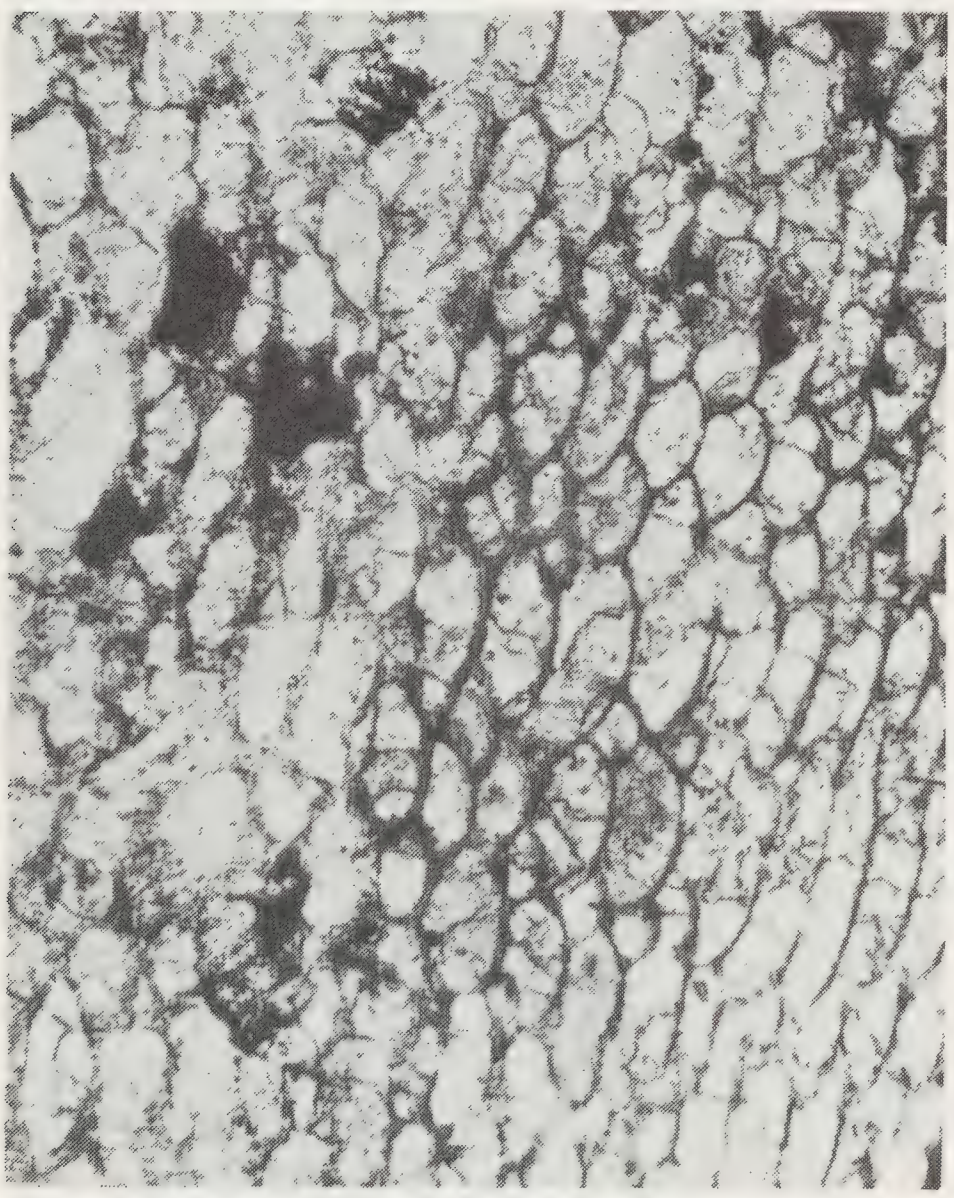


Figure 13. Vesicular microstructure of the Late Cambrian polyplacophoran *Matthevia variabilis* Walcott, Hoyt Limestone Member, Theresa Formation (Trempealeauan), near Saratoga Springs, New York, ×38, USNM 24598.

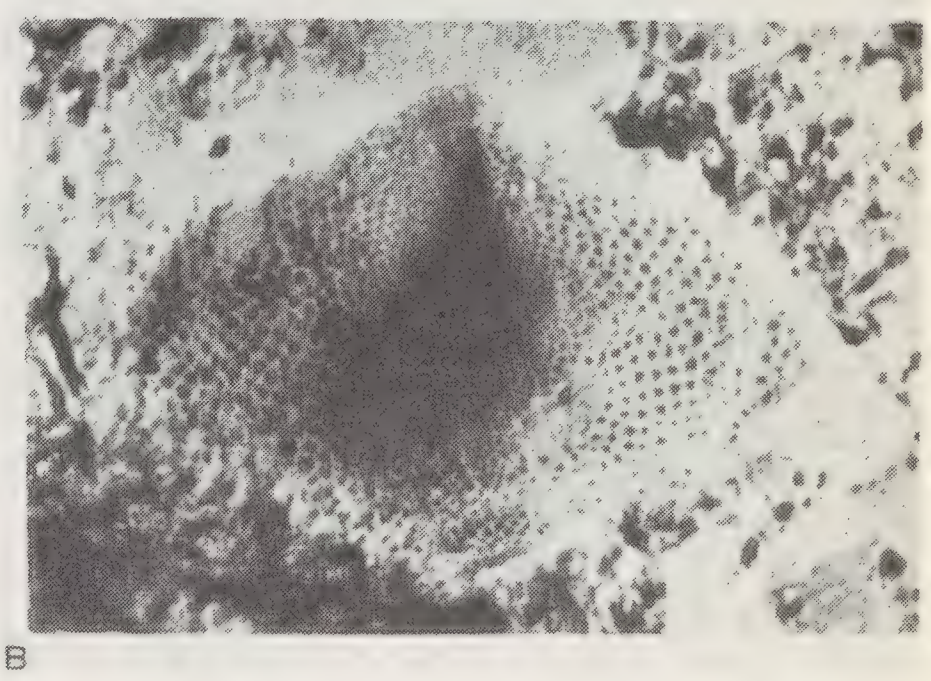


Figure 14. (A) *Matthevia variabilis* Walcott, lateral view of intermediate valve showing tubercles. Upper Cambrian, Hoyt Limestone Member, Theresa Formation (Trempealeauan), near Saratoga Springs, New York, ×4, USNM 258994. (B) *Preacanthochiton cooperi* Bergenhayn, external mold of intermediate valve showing tuberculate ornament. Upper Cambrian Eminence Dolomite (Trempealeauan), about 8 km south of Potosi, Missouri, ×8, USNM 259004.

and the two classes of mollusks that develop a bent or twisted gut. The Diasoma includes the classes Rostroconchia, Pelecypoda, and Scaphopoda or those conchiferan classes in which the gut is neither bent nor twisted. More importantly, the diasome classes are placed together because the Rostroconchia is the likely ancestor of the Pelecypoda and the Scaphopoda. Thus, in the subphylum Diasoma, the classes Pelecypoda and Scaphopoda are not direct descendants of the Monoplacophora.

The cyrtosomes are the ancestors of the diasomes, and both of these subphyla appeared and began to diversify within a few million years in the Early Cambrian. Because all cyrtosomes and diasomes are ultimately descended from a common ancestor that had a single dorsal valve, and was probably a monoplacophoran, the shells of the two subphyla contain homologous parts and structures.

Subphylum CYRTOSOMA

The classes Monoplacophora, Gastropoda, and Cephalopoda emphasize a conical univalved shell that is often twisted into a spiral. Because they have a relatively small single shell aperture, the anus is forced to lie close to the mouth and the gut is bent or twisted into a U-shape. These three classes specialized in non-infaunal living, although secondarily some have become infaunal. They ordinarily show little lateral compression of the body and are placed in the subphylum Cyrtosoma. Some Cambrian cyrtosomes do show lateral compression and are important as possible ancestors of the diasomes.

The taxonomic limits of the Monoplacophora are a matter of debate; Runnegar and Jell (1976) defined the class much more broadly than did Berg-Madsen and Peel (1978). Runnegar and Jell (1980) and Runnegar (in press b, c) have provided addi-

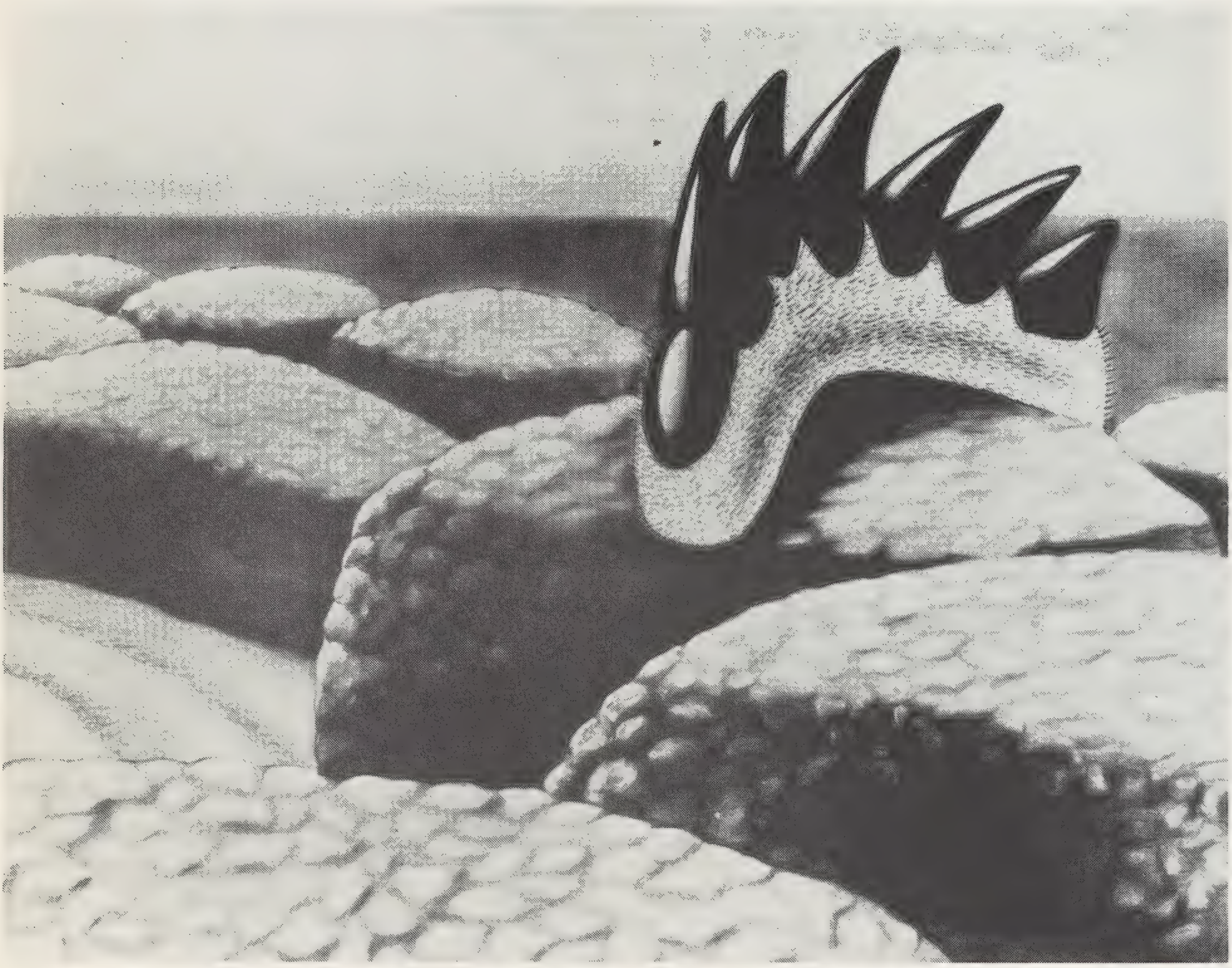


Figure 15. Artist's impression of *Matthevia variabilis* Walcott reconstructed as a polyplacophoran, grazing Late Cambrian intertidal stromatolites.

tional data on the classification, definition, and diversity of the Monoplacophora.

In the Early and Middle Cambrian, the monoplacophorans were diverse and sometimes abundant elements of the biota (Roz-anov *et al.*, 1969; Matthews and Missarzhevsky, 1975; Runnegar and Jell, 1976; and Yü, 1979). The monoplacophorans probably originated in the Precambrian, because in the Cambrian they already have diversified into cap-shaped shells, cone-shaped shells, cyrtoconic shells, and planispiral shells. At this time most monoplacophorans were probably epifaunal grazers that could clamp down the shell on the substrate. It seems likely that the Monoplacophora are descended from an aplacophoran-like spiculose ancestor that developed a low conical shell below the cuticle.

The helcionellaceans (Figure 19), Early and Middle Cambrian monoplacophorans, have tubular structures that provide insight into which end of the shell was anterior and which posterior. In living monoplacophorans, the apex of the shell is anterior and overhangs the head; this condition is termed exogastric. Ordovician monoplacophorans such as *?Macroscenella* cf. *M. montrealensis* (Billings), identified by E. L. Yochelson *in* Pojeta and Runnegar (1976) (Figure 20B), by analogy with the living forms have a planispiral larval shell overhanging the anterior end and an adult shell that is a tall cone. Helcionellaceans such as *Latouchella* Cobbold (Figure 20A) are cyrtoconic to planispiral, with the apex being regarded as anterior by comparison with *?Macroscenella* cf. *M. montrealensis*.

Helcionellaceans of the genus *Yochelcionella* Runnegar and Pojeta have a prominent snorkel projecting from the shell (Figure 21). In some species, such as *Y. cyrano* Runnegar and Pojeta and *Y. daleki* Runnegar and Jell (Figure 21B, C), the apex of the shell projects over the tube; these species are regarded as being exogastric. In other species, such as *Y. ostentata* Runnegar and Jell, the apex of the shell projects away from the snorkel (Figure 21A); these species are regarded as being endogastric, the snorkel being the homologous structure and, therefore, on the same side of the shell in all three species.

Yochelcionella ostentata is of particular interest in considering the origin of the cephalopods (Jell, 1978). In some specimens (Figure 21A), the snorkel forms the high point on the shell and its cavity is in line with the cavity of the body of the shell, rather

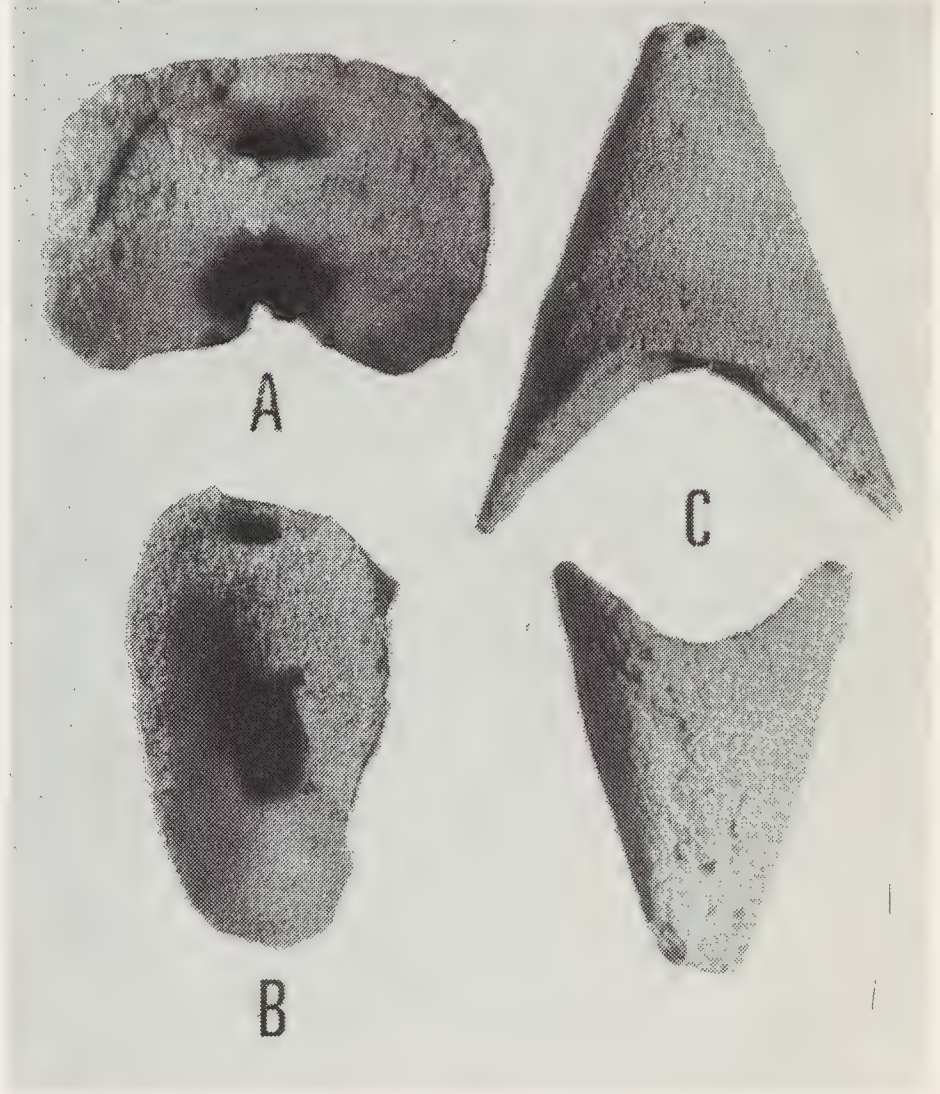


Figure 17. Gross morphology of the valves of the polyplacophoran *Matthevia variabilis* Walcott. (A) Ventral view of intermediate valve, showing deep muscle insertions, ×1.75, USNM 145312, Upper Cambrian, Wilberns Formation (Trempealeauan), Gillespie County, Texas. (B) Ventral view of tail valve showing deep muscle insertions, ×2, USNM 146896, Upper Cambrian, Nopah Formation (Trempealeauan), Charleston Peak Quadrangle, Nevada. (C) Dorsal view of two valves placed in the preferred orientation of hard parts of Yochelson (1966, p. B6), showing dorsal embayments of valves through which soft parts could protrude, ×1.75, USNM 145312 and 145313, localities the same as for figures A and B.

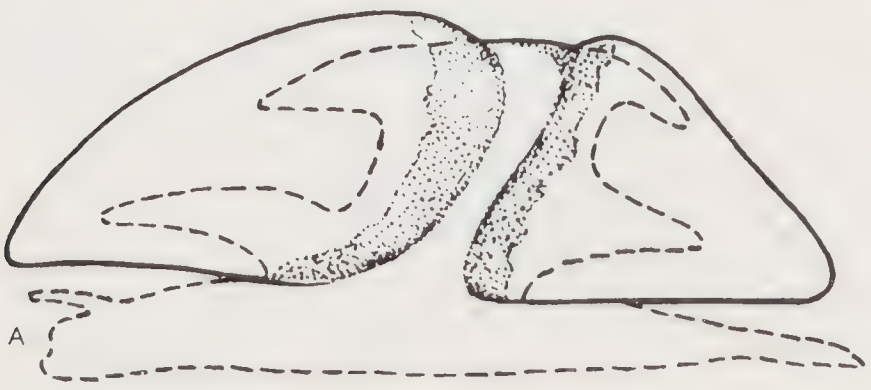


Figure 16. Reconstruction of *Matthevia variabilis* Walcott, preferred by Yochelson (1966, p. B6).

than being at nearly right angles to the shell, as in *Y. cyrano* and *Y. daleki* (Figure 21B, C). It is sometimes thought that cephalopods evolved from presumed endogastrically curved hypseloconid monoplacophorans (Yochelson, Flower, and Webers, 1973), some of which are known to have septa. The problem in cephalopod evolution is not in the derivation of septa, which are known in several classes of mollusks; rather, it is in the origin of the characteristic siphuncle of cephalopods. The siphuncle not only pierces the septa, it is a complex organ with blood vessels, nerves, mantle, conchiolin, and spicules of calcium carbonate. Such a complex organ seems unlikely to have formed around a strand of tissue that was not pulled forward at the time of the secretion of a septum as suggested by Yochelson, Flower, and Webers (1973, p. 293). On the other hand, a shell such as *Yochelcionella ostentata* (Figure 21A) already had a tube at the high point of the shell; the shell can be regarded as endo-

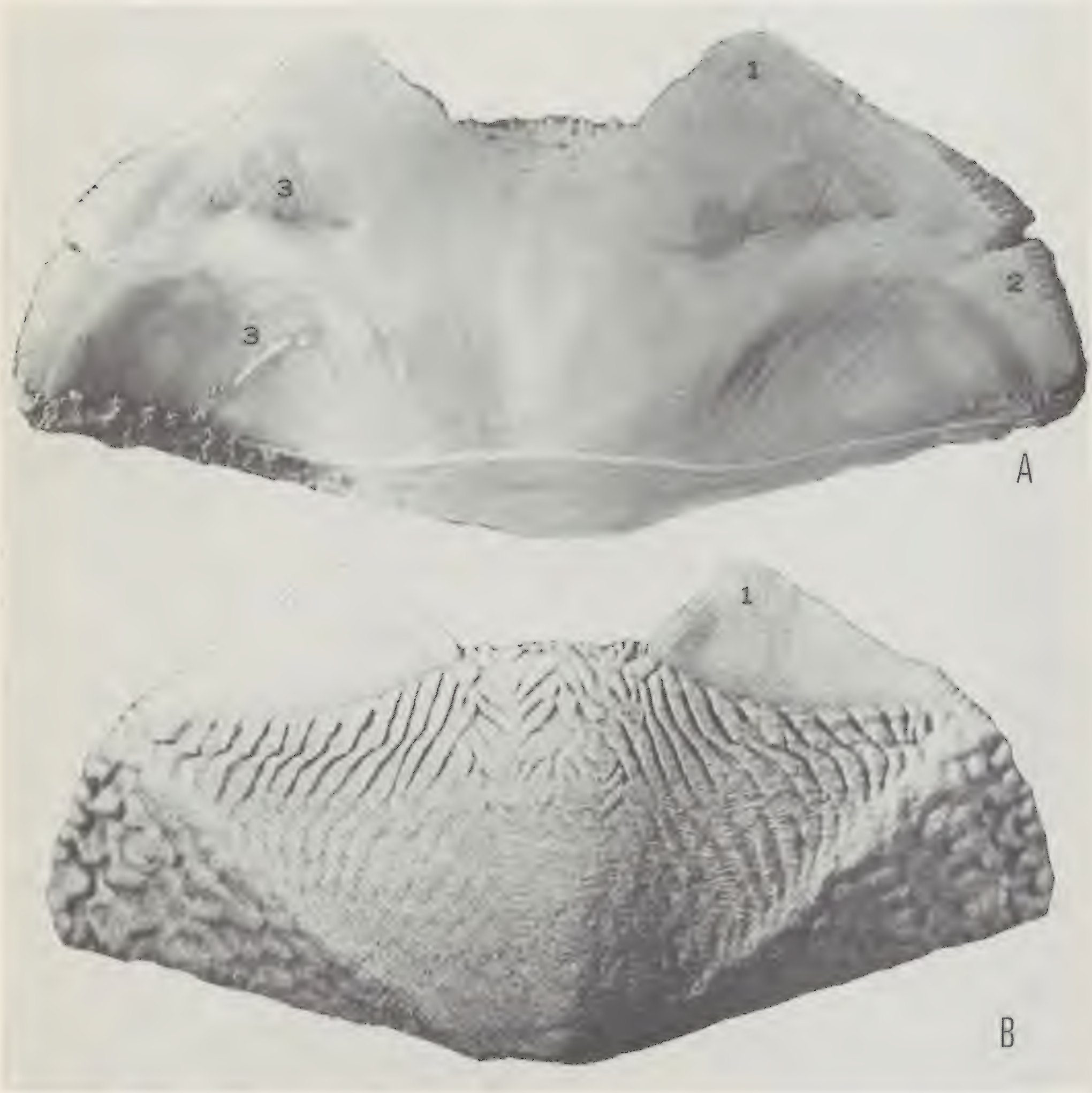


Figure 18. Interior (A) and exterior (B) views of a single intermediate valve of the living polyplacophoran *Chiton tuberculatus* Linné, ×5, USNM (Division of Mollusks) 621566. Anterior is up. (1) Sutural lamina or prong, (2) insertion plate, and (3) muscle scars.

gastric, and the shell is a high cone in which the gut would have to be bent into a U-shape. Such a shell could have been ancestral to cephalopods, the snorkel becoming a siphuncle after its end was sealed. Some of the earliest cephalopods are small orthocones or endogastric cyrtocones assigned to *Plectronoceras* from the Upper Cambrian rocks of China (Yochelson, Flower, and Webers, 1973, figs. 2). *Yochelcionella ostentata* is known from lower Middle Cambrian rocks in Australia (Runnegar and Jell, 1976). The recent description by Chen *et al.* (1979) of a highly diversified Late Cambrian cephalopod fauna from China suggests that cephalopods may have had a pre-Late Cambrian origin.

A few helically coiled species of mollusks are known from rocks as old as Early Cambrian; most of these are placed in the genera *Aldanella* Vostokova and *Pelagiella* Matthews (Figure 22). These genera have a worldwide distribution in Lower Cambrian rocks and there are no significant reasons for not considering these animals to be gastropods or near-gastropods. The known specimens of *Aldanella* suggest the presence of a peripheral sinus in the aperture (Rozanov *et al.*, 1969, pl. 3, fig. 14). One specimen of *Pelagiella* (Figure 22A-D) preserves muscle scars: paired unequal retractor scars are offset from one another; above them are arcuate insertions that may mark the dorsal edge of the mantle cavity. Interpreted in this way, the visceral mass was above the mantle insertion, and *Pelagiella* was partially torted. Torsion is the hallmark of gastropods; it takes the apex of the shell away from the head, making the animals endogastric. A sequence from helcionellaceans to pelagiellids to *Aldanella* (Figure 22E) may reflect increasing torsion and suggests how gastropods may have evolved from monoplacophorans.

There seems to be no need for a fully torted planispiral intermediate between monoplacophorans and helically coiled, torted snails. The development of helical

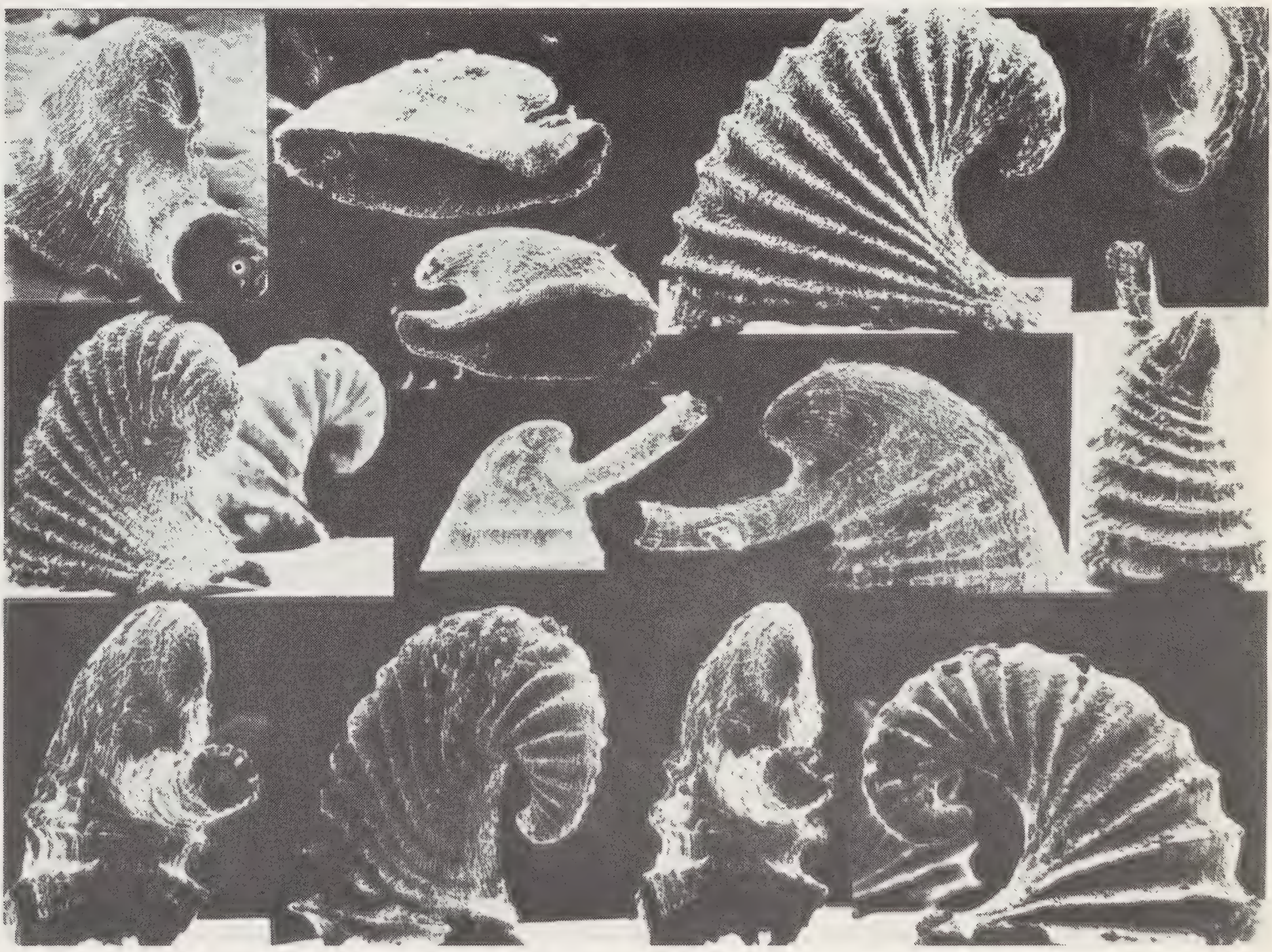


Figure 19. Montage of Middle Cambrian helcionellacean monoplacophorans described by Runnegar and Jell (1976). Figure constructed by Bruce Runnegar, University of New England, Armidale, N.S.W., Australia.

coiling by monoplacophorans may have caused torsion. Helical coiling allows an animal to produce the most compact body mass in the least possible space. In monoplacophorans, the shell is carried on the dorsal side, and paired dorsoventral muscles allow the shell to be clamped down against the substrate when necessary. Some of the tall strongly exogastric Cambrian helcionellaceans approach a planispiral condition (Figure 20A), and in order to produce a more compact body mass they may have evolved a helical (gyrogastric) shell. Such a

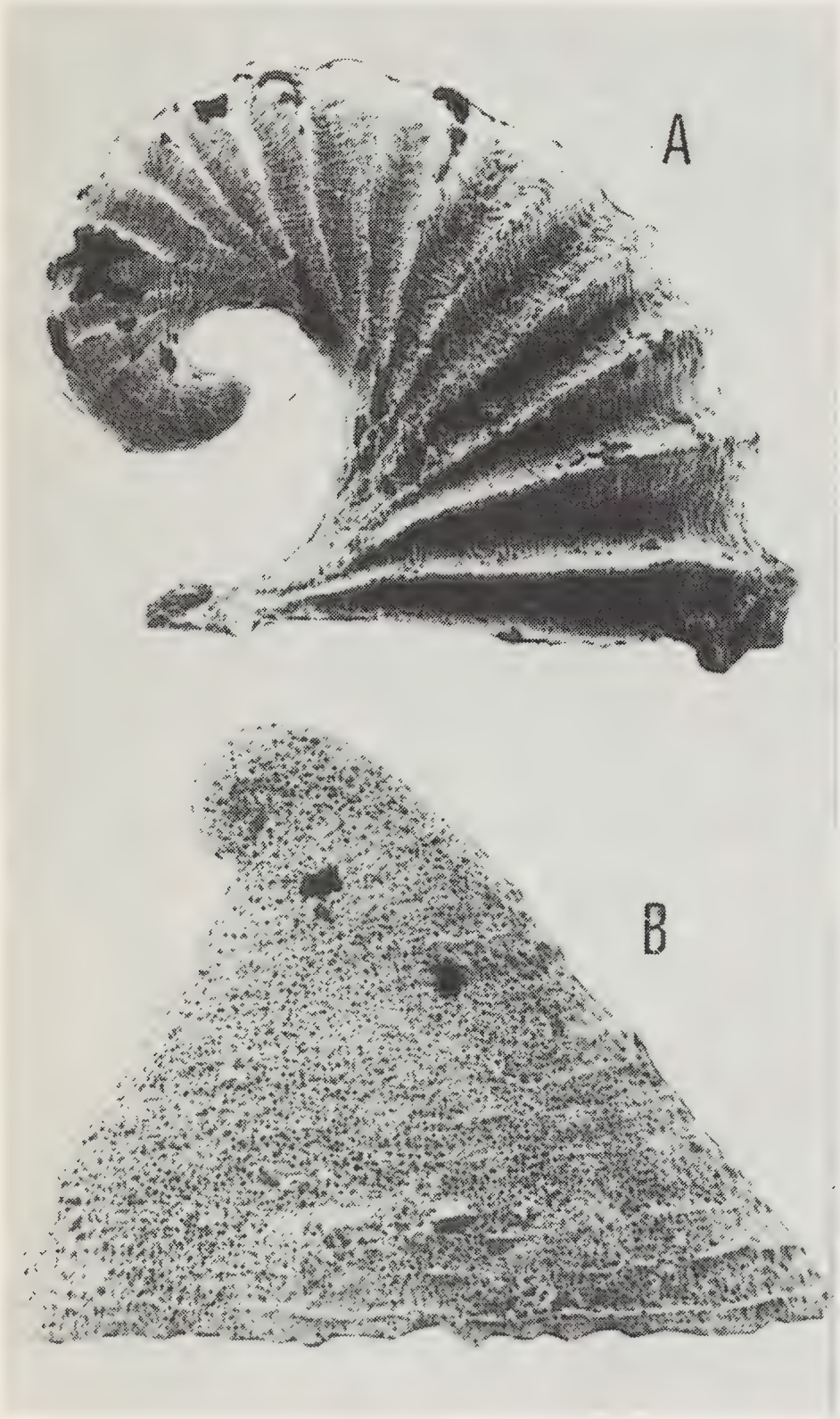


Figure 20. Comparison of shape and orientation of the Middle Ordovician monoplacophoran *?Macroscenella* cf. *M. montrealensis* (Billings) (B) from the lower part of the Chambersburg Limestone of Virginia, ×18, USNM 209378, with the Middle Cambrian helcionellacean *Latouchella accordionata* Runnegar and Jell (A) from the Coonigan Formation (Ordian) of New South Wales, Australia, ca. ×17, University of New England (UNE), Armidale, N. S. W., Australia.

Figure 21. Comparison of three species of the genus *Yochelcionella*. The snorkel of each species is regarded as the homologous structure on the same side of the shell in each case. (A) *Y. ostentata* Runnegar and Jell, apex of shell bends away from snorkel (endogastric), ×25, (UNE); (B) *Y. daleki* Runnegar and Jell, apex of shell bends toward snorkel (exogastric), ×28, (UNE); (C) *Y. cyrano* Runnegar and Pojeta, apex of shell bends toward snorkel (exogastric), ×19, USNM 204698. All specimens from the Coonigan Formation (Ordian), Middle Cambrian, New South Wales, Australia.

shell would have a spire that would stick out to the side, and the shell would tend to fall sideways. In order to keep a helical shell in place and crawl along the substrate, a gyrogastric monoplacophoran would have to exert continual muscular effort to keep the shell upright so that the whole body would not fall sideways. If such a shell could be rotated at the neck between the head/foot and the visceral mass, the spire would be pointed away from the head (endogastric), and the shell could be carried on top of the foot and dragged along behind. Thus, torsion may have been a functional adaptation to having the shell coiled in a helical spiral, and the processes of torsion and asymmetry need not have been separate episodes in the evolution of gastropods. Originally, torsion may have been much less than 180 degrees and the animal may not have been torted when withdrawn into the shell. Runnegar (in press b) gives a more extended consideration of torsion in Cambrian univalves.

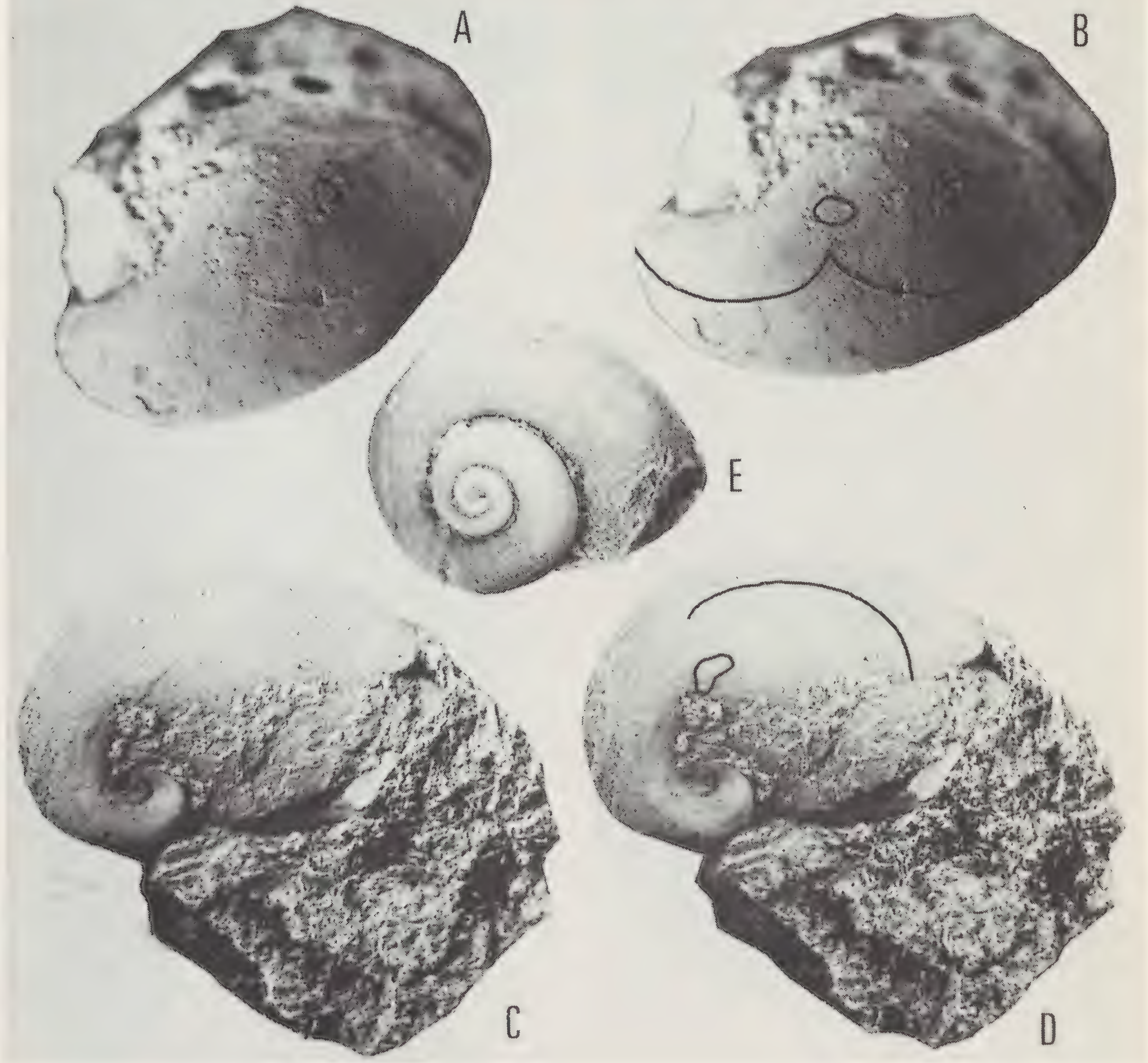


Figure 22. Helically coiled Cambrian shells. (A-D) Internal mold of *Pelagiella atlantoides* (Matthew), lateral views showing muscle scars, in figures B and D muscle scars are inked; Late Early Cambrian, *Protolenus* Zone, Hanford Brook, St. John County, New Brunswick, Canada, ×7.5, USNM 298724. (E) *Aldanella attleborensis* (Shaler and Foerste); Early Cambrian, Pleasant Beach, Cohosset, Massachusetts, ×7.5, USNM 26725.

Subphylum DIASOMA

The molluscan classes Rostroconchia, Pelecypoda, and Scaphopoda have a shell that is primitively open at both the anterior and posterior ends; this allows the gut to remain relatively straight, the mouth and anus widely separated from one another and opening at opposite ends of the shell. All three of these classes have specialized in infaunal living, and primitively lateral compression is a widespread feature of the group. The ancestral diasome class is the Rostroconchia, which probably arose from laterally compressed helcionellaceans and which gave rise to the Pelecypoda on the one hand and the Scaphopoda on the other. The subphylum Diasoma is used for these three classes because of their common origin, structure, and ecology; Runnegar and Pojeta (1974), Pojeta and Runnegar (1976, 1979), Pojeta (1978), and Runnegar (1978) have written extensively about diasome phylogeny.

Rostroconchs are pseudobivalved mollusks that have an uncoiled and untorted univalved larval shell and a bivalved adult shell in which one or more shell layers is continuous across the dorsal margin and which lacks a dorsal commissure (Figure 23). These mollusks range in age from Early Cambrian to Late Permian but are most diverse in Cambrian and Ordovician rocks.

The oldest known rostroconch is *Heraultipegma* Pojeta and Runnegar (Figure 24D-F) from the Lower Cambrian of France, Australia, Siberia, and China. It has a laterally compressed shell, anterior, ventral, and posterior shell gapes, and the pegma of younger rostroconchs (Figure 24D-F). The shell form of *Heraultipegma* was probably

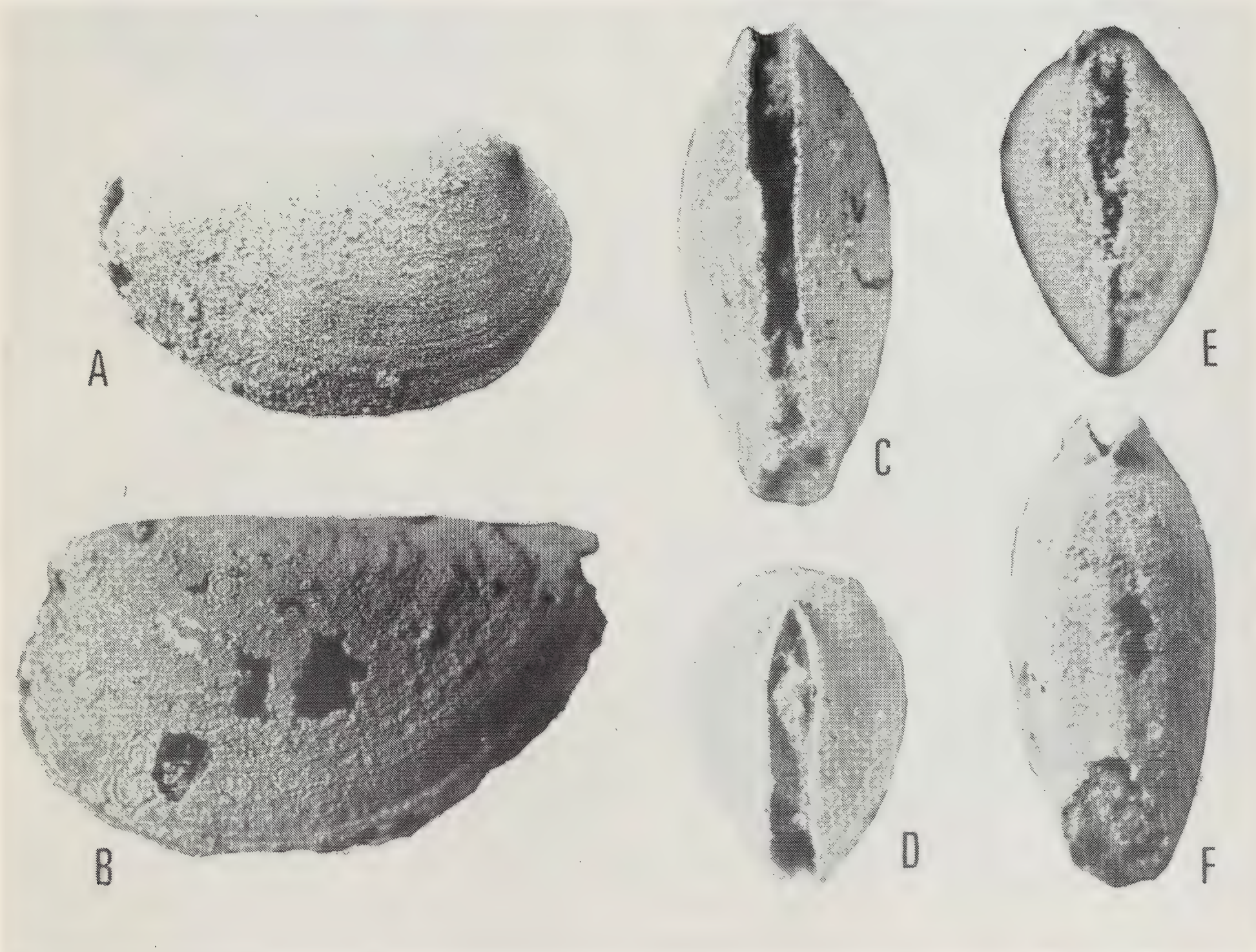
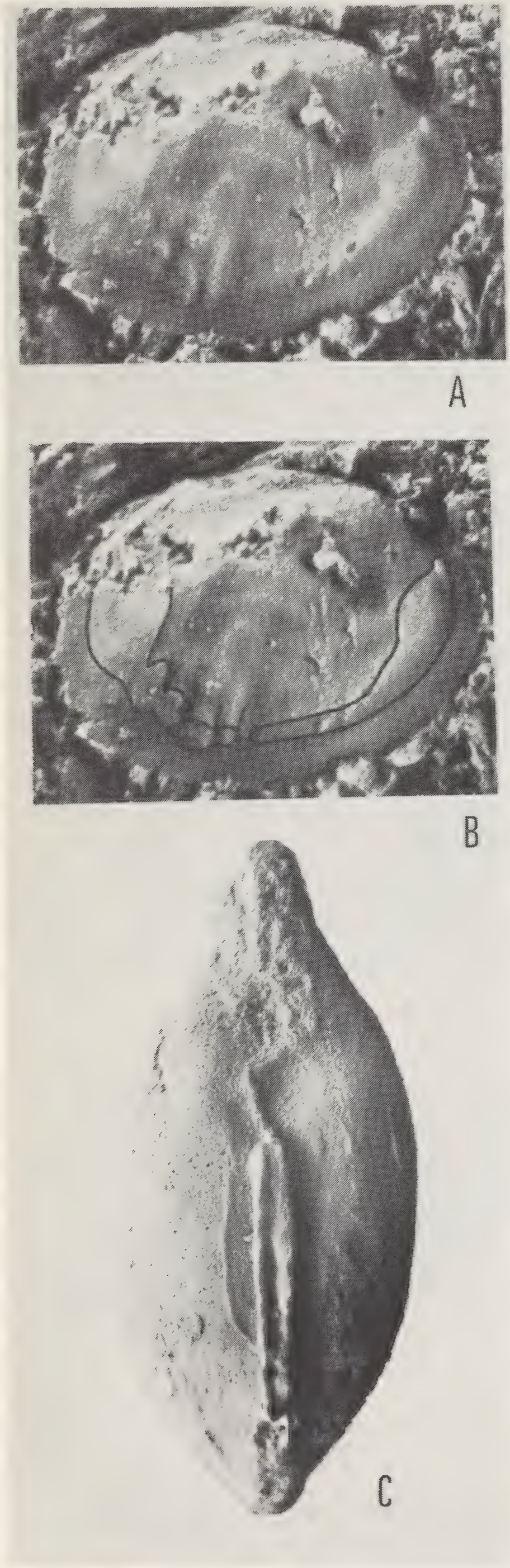


Figure 23. Gross external morphology of early rostroconchs, *Ribeiria australiensis* Pojeta and Runnegar, Mungerebar Limestone (Mindyallan), Upper Cambrian, Queensland, Australia. (A) right-lateral, (B) left-lateral, (C) ventral, (D) anterior, (E) posterior, and (F) dorsal views, ×4.5; Australian Bureau of Mineral Resources (BMR) 14671, 14672, and 14670.

derived from one of the laterally compressed helcionellacean monoplacophorans such as *Anabarella* Vostokova (Pojeta and Runnegar, 1976, pl. 17, fig. 8) and *Mellopegma* Runnegar and Jell (Figure 24A-C), which are mostly from Lower and Middle Cambrian rocks; recently, Tipnis *et al.* (1978) have identified an *Anabarella*-like organism from the Upper Cambrian rocks of Canada. These laterally compressed helcionellaceans are similar to *Heraultipegma* in size and lateral profile; they have a curved, rather than straight, apertural margin when viewed laterally and thus had anterior, ventral, and posterior shell gapes. Therefore, *Anabarella* and *Mellopegma* are regarded as morphological intermediates between monoplacophorans and rostroconchs. The lateral compression of the shell of some helcionellaceans may also have provided the mechanism by which epifaunal grazers, such as *Latouchella* (Figure 20A), could become infaunal burrowers and explains the infaunal mode of life in the Diasoma. Stasek (1972, p. 31) has suggested how the particulate material, which is collected by the cilia of the gills and has to be removed in non-suspension feeders, could be tapped as a food source by filter-feeding diasomes. He also noted that monoplacophorans, when they were beginning to exploit the use of food in the water column, may also have kept their radula and herbivorous habits; this explains the occurrence of a radula in scaphopods and suggests that primitive rostroconchs also had a radula.

Fordilla Barrande is the oldest known pelecypod; it has the musculature and dentition of younger clams, is fully bivalved rather than pseudobivalved, and occurs in Lower Cambrian rocks (Figure 25). Pojeta, Runnegar, and Kříž (1973); Pojeta and Runnegar (1974); Pojeta (1975, 1978); and Krasilova (1977) have provided the modern literature about *Fordilla*. Clam-shaped shells from the Upper Cambrian Frederick Limestone of Maryland are shown in Figure 26. According to J. E. Repetski, U. S. Geological Survey (written communication, September 1979), these shells occur below horizons containing the conodont *Proconodon-*

Figure 24. Comparison of the early compressed helcionellacean *Mellopegma georginensis* Runnegar and Jell (A-C), with the oldest known rostroconch *Heraultipegma varensalense* (Cobbold) (D-F). (A-C) oblique ventral, right-lateral, and oblique dorsal views; Currant Bush Limestone, upper Middle Cambrian, Queensland, Australia; A, B, ×38; C, ×75, USNM 298725, 298726. (D-F) Dorsal, ventral, and right-lateral views; Georgien (Lower Cambrian), St. Geniès de Varensal, France; D, F, ×30; E, ×38, USNM 298727, 298728.



tus muelleri Miller in the Lime Kiln Member of the Frederick; *P. muelleri* indicates a late Franconian to late Trempealeauan age.

It seems likely that pelecypods evolved from rostroconchs in the Early Cambrian by decalcification of the posterodorsal margin of the shell of rostroconchs. This decalcification would produce the elastic ligament of pelecypods; the change from a rostroconch to a pelecypod would be a biochemical one, expressed morphologically as an elastic dorsal margin. Such a margin would allow pelecypods to close without a gape and to burrow more efficiently than rostroconchs probably could. When living pelecypods burrow, their valves are pressed against the sides of the burrow by the opening thrust of the ligament. Subsequently, as the foot forms the pedal anchor, the sediment is loosened by ejection of water from the mantle cavity, produced by contraction of the adductor muscles. Contraction of the pedal muscles then pulls the animal into the loosened sediment (Trueman, 1968). Rostroconchs were probably less efficient burrowers than pelecypods because they lacked a ligament and adductor muscles (Pojeta, 1979).

The Middle Cambrian species *Myona? queenslandica* Runnegar and Jell suggests that rostroconchs did give rise to pelecypods by decalcification of the dorsal margin. This species (Runnegar, 1978, pl. 2, fig. 26) has a univalved protoconch and a bivalved adult shell and is thus a rostroconch by definition. However, its middorsal line is clearly differentiated from the rest of the shell and is unlike the middorsal line of other rostroconchs (compare Runnegar, 1978, pl. 2, figs. 26, 28, with Figure 24D herein). In addition, some specimens of *Myona?* are flexed along the dorsal margin

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Figure 25. (A, B) *Fordilla troyensis*, right valve of internal mold showing muscle scars; in B the scars are inked; Lower Cambrian, Troy, New York, ×11.5, USNM 15,372. (C) *Fordilla sibirica* Krasilova, dorsal view of internal mold showing dentition; Lower Cambrian (Atdabanian), Lena River, Siberia, ×31.5, USNM 247821. A. Yu Rozanov (Paleontological Institute, Akademia Nauk SSSR) kindly provided the specimen of *F. sibirica*.

indicating, that the margin was elastic and acted as a ligament (Runnegar and Jell, 1976, fig. 8D7).

The morphological sequence leading from a helcionellacean such as *Latouchella* to laterally compressed helcionellaceans like *Anabarella* and *Mellopegma,* to rostroconchs like *Heraultipegma,* to rostroconchs like *Myona?* and finally to pelecypods like *Fordilla* (Pojeta, 1978) shows empirically how a bivalved shell could arise from a univalved shell (Figure 27).

The last class to be considered is the Scaphopoda. The oldest known fossil scaphopod (Figure 28A) is from the uppermost Middle Ordovician rocks of Kentucky and is placed in the genus *Rhytiodentalium* Pojeta and Runnegar (1979).

A rostroconch genus called *Pinnocaris* Etheridge (Figure 28C), which lived from the latest Cambrian to the latest Ordovician has anterior and posterior shell gapes (Pojeta and Runnegar, 1976), no dorsal commissure (Pojeta and Runnegar, 1976; Pojeta, Gilbert-Tomlinson, and Shergold, 1977), and the valve edges touching at the ventral commissure. *Pinnocaris* looks remarkably like a scaphopod and probably lived like one, embedded in the sediment, with the posterior end protruding (Runnegar, 1978, fig. 1).

The larval shell of *Pinnocaris* is near the anterior end of the conch, and growth is predominantly in a posterior direction (Figure 28C). In scaphopods, all growth is directed anteriorly, and they probably did not evolve by the simple fusion of the ventral margin of *Pinnocaris,* because a change in the dominant growth component from posterior to anterior was required. In the Lower Ordovician rocks of Australia, *Pinnocaris?* sp. C Pojeta and Gilbert-Tomlinson is present (Figure 28B). This species is nasute anteriorly and has a significant anterior growth component. *Pinnocaris?* sp. C is intermediate stratigraphically and morphologically between Late Cambrian species of *Pinnocaris* and *Rhytiodentalium* in the Middle Ordovician (Figure 28).

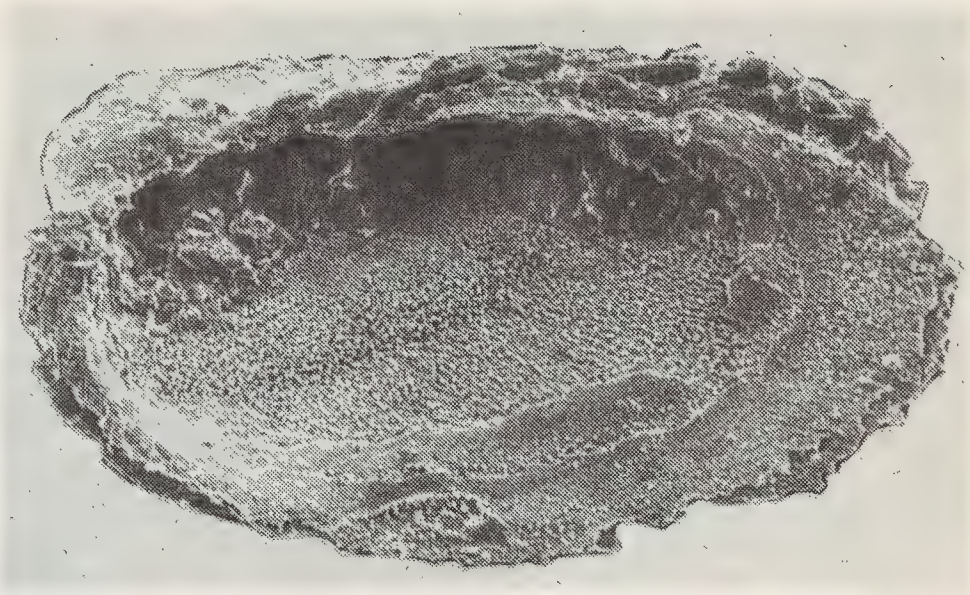

Figure 26. Possible Late Cambrian pelecypod from the Lime Kiln Member, Frederick Limestone, near Buckeystown, Maryland. ×100, USNM 298729.

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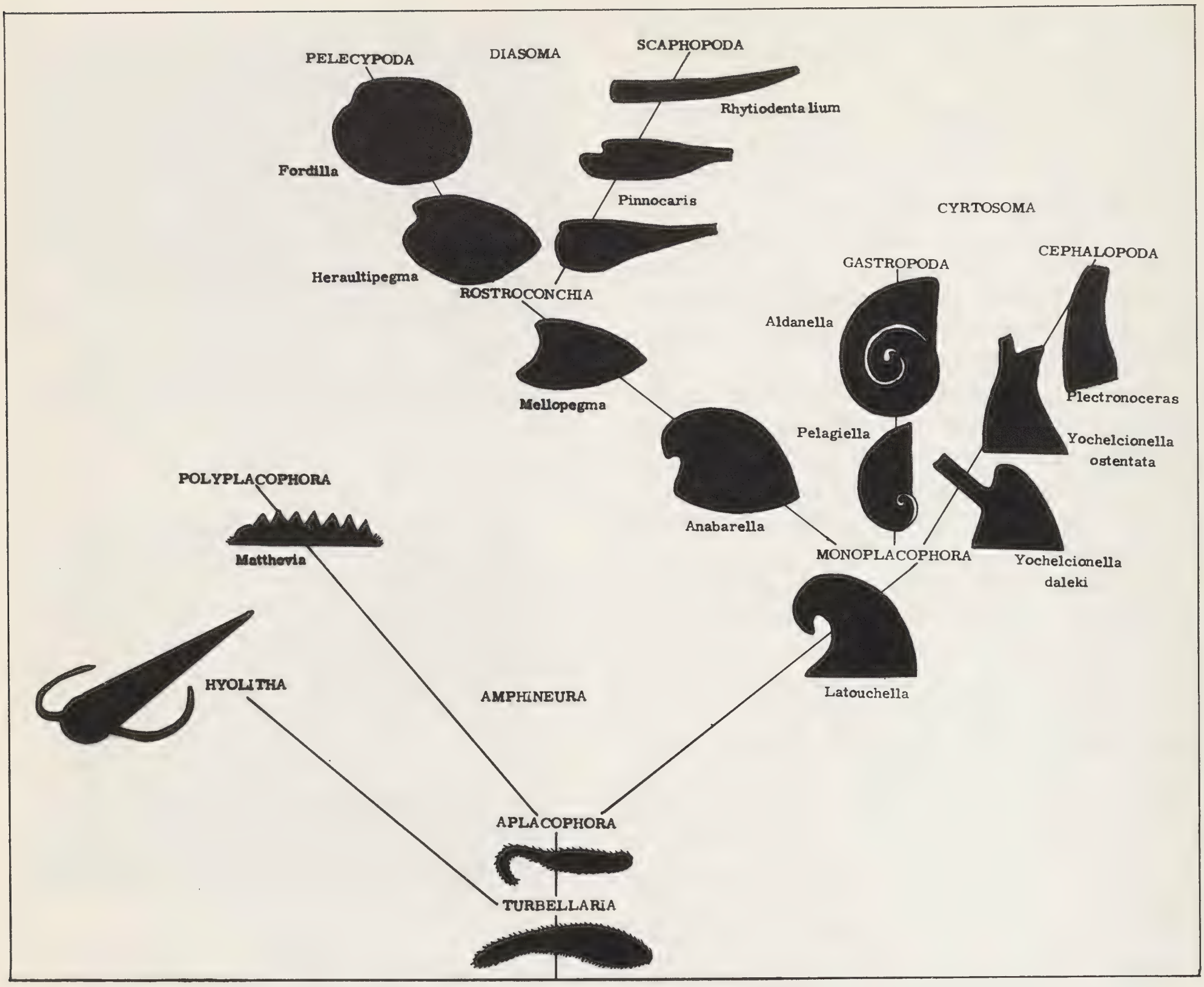

Figure 27. Diagrammatic representation of early molluscan evolution.

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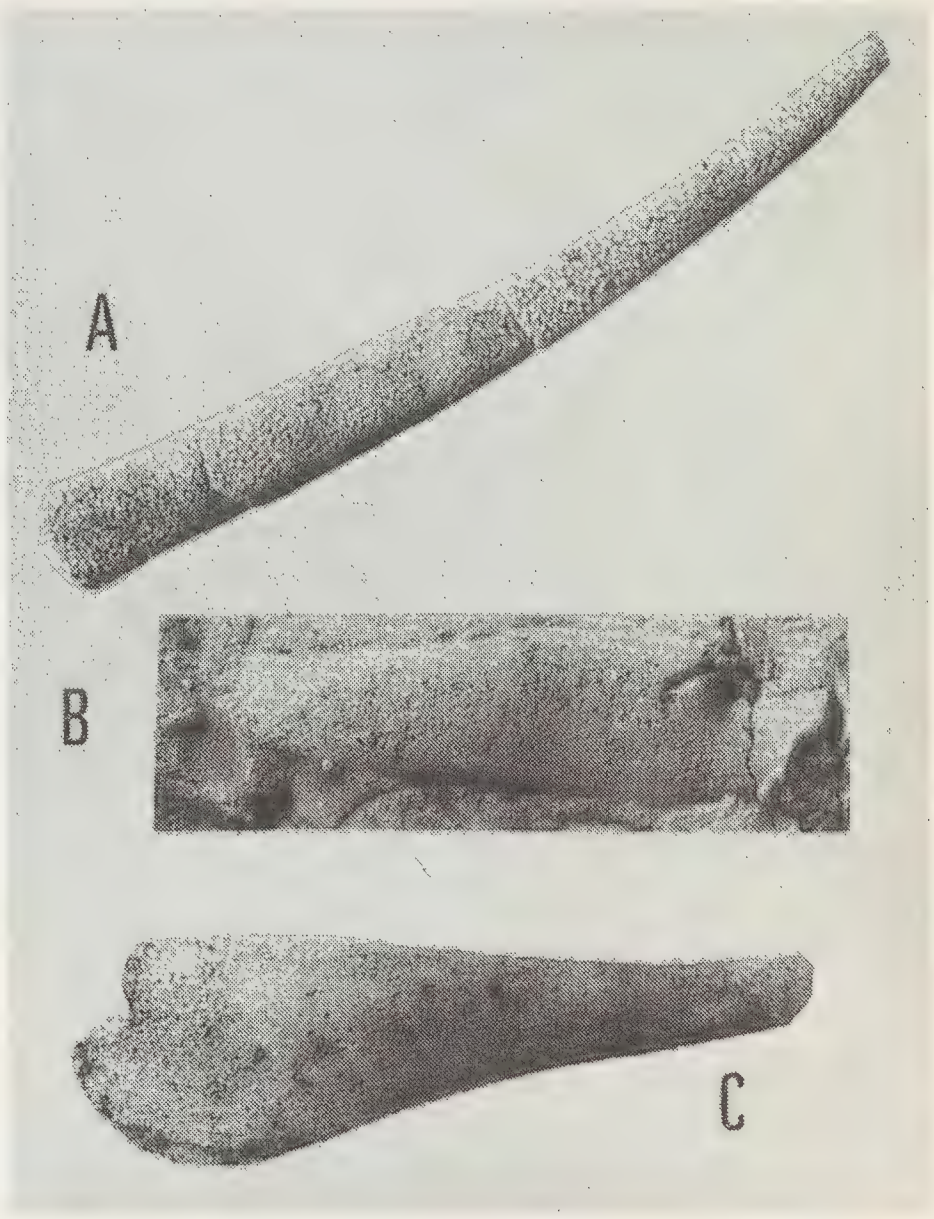

Figure 28. Origin of scaphopods. (C) Left-lateral view of composite mold of *Pinnocaris wellsi* Pojeta, Gilbert-Tomlinson, and Shergold, which is a rostroconch having a dominant posterior growth component, from the Payntonian (Upper Cambrian) part of the Pacoota Sandstone, Northern Territory, Australia, ×1.2, BMR 14746. (B) Right-lateral view of composite mold of *Pinnocaris?* sp. C Pojeta and Gilbert-Tomlinson, which is a nasute rostroconch having a significant anterior growth component, from the Arenigian (Lower Ordovician) part of the Pacoota Sandstone, Northern Territory, Australia, ×2, BMR 15593. (A) Left-lateral view of a silicified specimen of *Rhytiodentalium kentuckyensis* Pojeta and Runnegar, a scaphopod having all growth in an anterior direction, from the Middle part of the Lexington Limestone (Shermanian), Middle Ordovician, central Kentucky, ×2.8 USNM 254392.

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LATE QUATERNARY MICROPROBLEMATICA *(VOORTHUYSENIELLA)* FROM A MISSISSIPPI DELTA MUDLUMP

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I. ABSTRACT

The micro-fauna and flora of a Mississippi Delta mudlump sample dated as 15,500 years B.P. (C^{14}) is detailed. The age of the sample is discussed with reference to the chronostratigraphic and biostratigraphic problems of the Holocene-Pleistocene boundary. Four specimens of *Voorthuyseniella* Szczechura (1969) recovered permit some previously recorded forms of this taxon, originally left in open nomenclature, to be taxonomically stabilized into three new species: *Voorthuyseniella baileyi*, *V. greigi*, and *V. williamsae*.

II. INTRODUCTION

The capacity to classify an organism affords the neontologist or paleontologist a certain degree of satisfaction. Whether the classification utilized is natural (biologic) or artificial (morphologic) will depend upon the philosophy of the individual, which, in turn, is often determined by the state of knowledge concerning the organism. Conversely, the inability to classify an organism often leads to frustration but, as pointed out by Hantzchel (1975, p. W153) this inability need not detract from the stratigraphic value of the organism. Further, the paleoecological usefulness of such an organism need not be ignored.

Since the middle of the past decade a number of Tertiary forms of unknown affinities have appeared in print. These forms exhibit all types of morphologic characters ranging from specimens with subspherical to triangular tests, to irregular, and even horseshoe shaped forms. Body openings vary in number from one to four or more. In other words, these objects are highly variable. The described taxa include *Bicornifera* Lindenberg 1965, *emend.* Keij, 1969; *Bolboforma* von Daniels and Spieglar, 1974;

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Dicasignetella Keij, 1969; *"Guttulae"* Hiltermann and Schmitz, 1968; *"Parvangulae"* Hiltermann and Schmitz, 1968; *Spinophenia* Szczechura, 1969; *Triangulina* Quilty, 1970; *Urnulella* Szczechura, 1969; *Voorthuyseniella* Szczechura, 1969; and *Bifissurinella* Poignant and Ubaldo, 1973. Keij, 1977, ascribes two of these forms, *Bicornifera* and *Bifissurinella* to bryozoa.

Voorthuyseniella Szczechura, 1969, is an organism which, since its introduction to the scientific community in 1949 by J. H. van Voorthuysen as *Lagena-x*, has yet to be classified with any confidence. Keij (1970, p. 480) declared "no positive statement can be made about the systematic position of *Voorthuyseniella*." As stated, the biologic affinities of the organism are not established, and, indeed, the nature of the form is unknown as to whether it is an entity in itself or whether it is part of a higher organism.

Attention given to this organism can be regarded chronologically, based on geographic areas of interest. The introduction of the taxon as *Lagena-x* and reported European and Far East occurrences represents the first phase of activity. This period lasted from 1949 to 1967, as evidenced by the following occurrences: Netherlands (Voorthuysen, 1949); Holland (Voorthuysen, 1956); Portugal (Ferriera and Rocha *in* Voorthuysen, 1956); Germany (Ellerman, 1960); Belgium and France (Bignot, 1962); Taiwan (Huang, 1962); W. Germany (Indans, 1962; Kummerle, 1963); South China Sea (Keij, 1964); W. Germany (Kummerle and Gunawardena, 1967).

The formalization of *Lagena-x* as *Voorthuyseniella* by Szczechura in 1969 represents the start of a second period of activity. In this phase can be placed the monographic work of Keij, (1970).

The most recent phase shows an increased interest in New World occurrences while continued interest in European occurrences is evidenced by the following reports: Belgium (Willems, 1972, 1975); France (Poignart and Ubaldo, 1973), and Germany (Spieglar, 1976).

The report by Keij (1970) provided the catalyst for interest in this form in North America. Gulf Coast records have been provided by the following: Alabama (Keij, 1970; Haman and Kohl, 1976a); Mississippi (Keij, 1970); Texas (Keij, 1970; Haman and Kohl, 1976b; Haman, 1977, 1978; and Louisiana (Haman, 1978, and this report).

The purpose of this article is to document the occurrence of *Voorthuyseniella* in late Quaternary sediments obtained from a structurally complex area in a unique geologic and geomorphologic province, namely a mudlump off the Mississippi Delta.

The recovery of these specimens of this taxon now allows previously described forms, left in open nomenclature, to be taxonomically stabilized by formal naming. This procedure will provide uniformity to the Gulf of Mexico occurrences.

III. DISCUSSION

The Mississippi Delta province is characterized by "mudlump" development. The mudlumps are generated by diapiric action due to differential sediment loading. Local distributary mouth bar sands are rapidly deposited over plastic pro-delta and marine clays. The more dense sands cause diapiric action by the underlying less dense clays, which are intruded into the overlying sands. Clay movements of 200 meters vertical displacement have been documented (Coleman, 1976). The classic model of a delta front advancing over the underlying sediments, as illustrated by Morgan (1961), is complicated by low angle thrust faults as detailed by Morgan *et al.* (1963). Mudlumps, due to their sedimentological character, are relatively short-lived phenoma. After development they are either incorporated into the advancing delta or are rapidly destroyed by wave action. Detailed discussions on mudlumps are to be found in Morgan (1961), Morgan *et al.* (1963), and Coleman (1976).

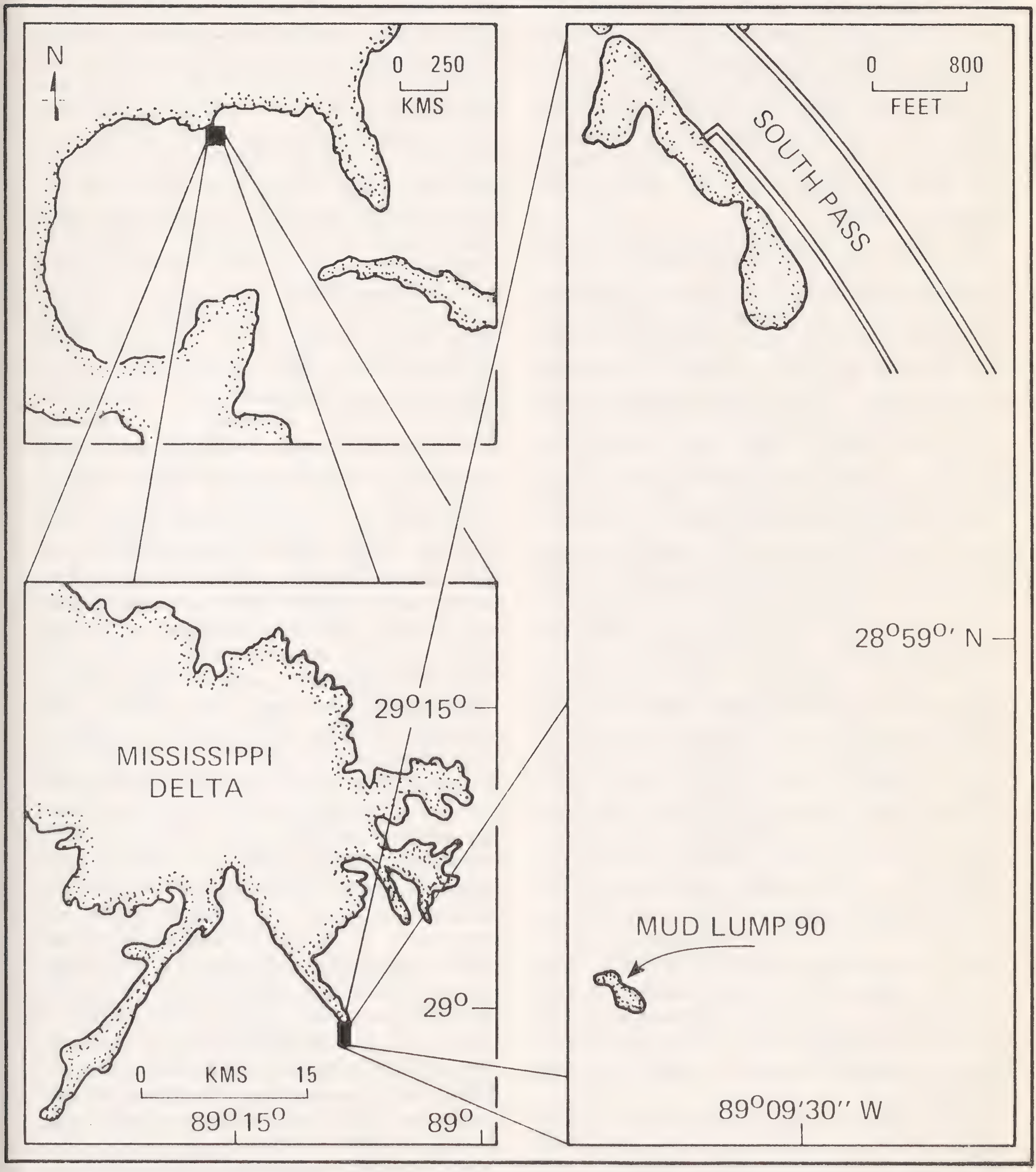
In December, 1976, a sample was collected from mudlump 90, south west of the mouth of South Pass in the Mississippi Delta (Text-Figure 1). The sample was essentially a shell hash with marl and proved to be extremely rich in microfauna, particularly foraminifera. A detailed analysis was made of the microfauna and microflora in an attempt to gain a better understanding of the depositional environment and age of the sample. During this examination the *Voorthuyseniella* specimens were obtained.

Sample Age with Reference to the Holocene-Pleistocene Boundary

The subject sample is coeval with the shell horizon of Coleman (1976) (J. P. Morgan, personal communication, 11/4/78).

This horizon is regarded as an excellent subsurface stratigraphic marker throughout the entire delta region (Coleman, 1976, p. 48). Numerous radio-carbon analyses have dated the shell layer at 13,400-16,600 years B.P. (Coleman, 1976), and the subject sample has been dated as 15,500 years B.P. (Morgan, personal communication). This date approximates to the C^{14} dates of this horizon in Borehole SP-1 "B" of 15, 175 + 575 and 15,575 + 500 years B.P. (Morgan *et al.*, 1963).

The dating of the Holocene-Pleistocene boundary in the Gulf of Mexico and elsewhere in the world is still open to question, and numerous differing dates and/or da-



Text Figure 1. Location of Mudlump 90 in relation to the Mississippi Delta in the Gulf Coast province.

tums exist in the literature. Poag and Sweet (1972) reviewed the INQUA subcommission recommendations and the European and U.S. viewpoints. Berggren and Van Couvering (unpubl.) note that the date of *ca.* 10,000 years is referred to by many geologists as the Holocene-Pleistocene boundary. Van Eysinga (1975) may be quoted as an example. The same authors mention that the climatological base of the Holocene may extend to 13,000 years B.P. They emphasize that climatically controlled cycles cannot serve as a basis for drawing chronostratigraphic boundaries. The late Pleistocene-Holocene interval in the Gulf of Mexico is characterized by evidence of rapidly changing climatic conditions and allied water mass oscillations.

Kennett and Huddlestun (1972) defined 18 zones in the late Pleistocene-Holocene section based on foraminiferal assemblages, most of which are related to paleoclimatic changes. These authors emphasize (footnote 3, p. 44) that these zones are biostratigraphic and not chronostratigraphic in nature. In defining the zones these authors note that although each zone is characterized by a distinct faunal assemblage, in most cases the boundaries between the zones are indistinct and arbitrarily placed at gradational faunal changes. In fact, they indicate that some of their subzone boundaries (*e.g.*, Y1-Y2, late Pleistocene) are more distinct than their zone boundaries (*e.g.* Y-Z, late Pleistocene-Holocene). The Y-Z boundary, by definition, is based on the first consistent occurrence of the *Globorotalia menardii* (d'Orbigny) plexus. In other words, the Z interval (Holocene) is recognized by the presence of warmer water planktics such as *Globorotalia menardii* (d'Orbigny), *Pullenia-atina obliquiloculata* (Parker and Jones) to name just two, and a distinct decrease in abundance of the cooler water forms such as *Turborotalia inflata* (d'Orbigny). The reverse is the case in the Y (Wisconsin) interval. Kennett and Huddlestun (1972) state that the most distinct faunal change associated with the Holocene warming does not coincide with the Y-Z boundary as defined, but occurs slightly earlier during the latest Wisconsin.

While Kennett and Shackleton (1974) date the Y-Z paleontological boundary at 11,000 years B.P. they note (1975, p. 150) that this boundary may be slightly younger in the Gulf than in the Caribbean (11,000 ± 500 years B.P.) due to the delayed migration of tropical *Globorotalia menardii* (d'Orbigny) into the cooler Gulf near the end of the last glaciation.

Kennett and Shackleton (1974, 1975) documented evidence to record the effects of the Laurentide ice sheet meltwaters in late Pleistocene cores in the Gulf of Mexico. The meltwater effect resulted in oxygen isotope anomalies in core measurements and these allowed the authors to reconstruct a paleoclimatological chronosequence. The isotopically negative meltwaters were believed to have first affected the Gulf of Mexico possibly as early as 16,000-17,000 years B.P., or at least by 14,500 years B.P. The incursion peaked around 13,500 years or as late as 12,800 years B.P., followed by a decline in meltwater discharge with normal marine isotopic composition being restored by 11,500 years B.P.

If C^{14} dating could be regarded as infallible, then the date of the subject sample (15,500± years B.P.) would be of late Wisconsin age (subzone Y1). C^{14} dating has, however, been subject to criticism. Broecker and Bender (1972) questioned the accuracy of dates between 5,000 and 25,000 years B.P. and regarded dates > 25,000 years B.P. as highly suspect. Stapor and Tanner (1973) stated that the 6,000 year B.P. datum based on the bristle-cone pine curve represents the limit of reliable C^{14} dating. Morgan (1963) and Poag and Sidner (1976) rejected some of their own C^{14} dates as unreliable due to carbon contamination.

Representatives of the *Globorotalia menardii* (d'Orbigny) plexus are evident in the subject sample. Although a single sample precludes evaluation of occurrence persistency (criterion of Zone Z recognition), the geologic relationship of the sample to the stratigraphic interval in question may assist in determining the reliability of the occurrence. As stated earlier, this sample is equivalent to the shell horizon of Coleman (1976). The shell horizon was encountered in a corehole (Borehole SP-1 "B") in the South Pass area of the delta region at −348.8′ to −349.8′ (Morgan *et al.*, 1963). Andersen (*in* Morgan *et al.*, 1963) recorded *Globorotalia menardii* (d'Orbigny) as persistent in occurrence in this borehole from a depth of −350′ to the top of the core. The taxon ranged in abundance (of total planktics) from 4-15% (−350′ to −230′±) and from 1-4% (−230′± to the core top). This interval,

including the shell horizon, is by definition of Zone Z (Holocene) age. The presence of the calcareous nannofossil *Emiliania huxleyi* (Lohmann) in the present sample supports this age assignment. This sample also yielded specimens of *Globorotalia ungulata* Bermudez, *Globorotalia tumida* (Brady) and *Globorotalia truncatulinoides* (d'Orbigny) (with deep umbilical pit) which, while not definitive, tend to substantiate the Holocene age (see Stainforth *et al.*, 1975). Specimens of *Globigerinoides ruber* (d'Orbigny) are common in the sample. Of these specimens, 10-15% are colored red, pink, and pink-amber, the remainder being white. Parker, 1973, used pink *Globigerinoides ruber* (d'Orbigny) and pink *Globigerina rubescens* Hofker to recognize the Holocene in low latitude Atlantic localities. This pink coloration has apparently been utilized by some Gulf Coast laboratories for recognition of the Holocene. Bé and Tolderlund (1971) did not directly comment on the stratigraphic value of *Globigerinoides ruber* (d'Orbigny) but noted that pigmented forms appear to be restricted to the North and South Atlantic. They also made the observations that this form is predominantly associated with near land mass populations and is temperature (seasonally) controlled. Luz and Bernstein (1976) noted that the pink coloration of *G. ruber* (d'Orbigny) appeared to fade rapidly with depth in cores they examined from the eastern Mediterranean. They did, however, utilize the pink forms to identify Recent core tops. Kennett, 1976, reviewed the pigmentation (pheophytin) distribution in tests of both *Globigerinoides ruber* and *Globigerina rubescens* and stated that the distribution is related to seasonal changes. Consequently it can be stated that the stratigraphic value of the pigmented *Globigerinoides ruber* is still open to question, the form is seasonally controlled, and the pink coloration is more dominant with warmer temperatures.

The total planktic faunal composition (see appendix) would, following the techniques of Bé and Tolderlund (1971), suggest a subtropical to tropical regime, which would be consistent with a Holocene warming following the last glaciation. Conversely, by relating such a temperature increase to the curve of Emiliani (1971) it could be suggested that this paleoclimatological regime could have begun in the latest Wisconsin (subzone Y1). Poag and Sidner (1976) made the statement that the C^{14} dates for their *crassaformis* facies "would indicate that the post Wisconsin rise in sea level began earlier than generally has been reported." This is not inconceivable bearing in mind the statement by Kennett and Huddlestun (1972) concerning the Holocene warming.

Consequently the age of this sample is problematic. If the C^{14} age of 15,500± years B.P. is correct, the sample is of Wisconsin age. The fauna is a warm water fauna and may be equivalent to that portion of the section affected by the Laurentide ice sheet meltwater (17,000±-13,500± years B.P.). If this is correct, the use of the persistent *Globorotalia menardii* plexus as definitive for Zone Z (Holocene) recognition is suspect. On the contrary, if the *G. menardii* zonal criterion is accepted, then the sample is of Holocene age and the C^{14} date is suspect, as other workers have stated for radiometric dates of this magnitude.

Reference may be made to other studies concerned with the Gulf of Mexico late Quaternary with its allied chronostratigraphic and biostratigraphic problems as a means to determine the correct stratigraphic placement of the sample. In recent years the works of Poag and his colleagues have been instrumental in attempting to solve some of these problems (Poag, 1971, 1972, 1973a,b; Poag and Sweet, 1972; Poag and Carney, 1974; Poag and Sidner, 1976; Poag and Valentine, 1976).

Poag and Sidner (1976) recognized three biofacies in their zonation of the West Flower Garden Bank area, offshore Texas. The lowest sequence was termed the basal Inflata Facies related to the late Pleistocene cool water regime. The top sequence was termed the upper Cultrata Facies, characteristic of the Holocene outer shelf environment. Between these two facies occurred the Crassaformis Facies, which was stated to represent a deepening sea that had warming surface waters. A historical sequence of the facies was presented but a definitive Pleistocene or Holocene age for the Crassformis Facies was not given. It was simply stated to be a "transition between the cool Inflata Facies and the warmer overlying Cultrata Facies" (p. 23). It was noted that during the final deposition stages of the Crassaformis Facies sea level stood at approximately −53 m. If this depth is related to Figure 8-20 of Poag and Sweet (1972), it would equate to the 60 m stillstand

of Holocene age. Poag and Valentine (1976) in their biostratrigraphic and ecostratigraphic zonation of the Pleistocene sediments of the Texas-Louisiana basin equate the *G. cultrata* facies referred to above to *G. menardii* (Fig. 13) and *G. ungulata* (Fig. 2). This zone is referred to as Holocene while the *G. crassaformis* zone is regarded as Pleistocene (Fig. 2). In the same publication on Figure 12, however, the *Globorotalia crassaformis* zone is shown to range from subzone Y2 (Wisconsin) to subzone Z2 (Holocene). The same authors state (p. 197) "we conclude that the *Gl. ungulata* Zone was deposited during the last 10-12 × 10^3 years and represents the Holocene." On their Figure 12, C^{14} dates for the lower part of this zone (basal Holocene) of 13,000, 13,150, and 15,000 years B.P. are included.

In summary, the Holocene-Pleistocene boundary in the Gulf of Mexico is not clear-cut. This is in part due to discrepancies between the cycles and zonations recognized in deep water sediments being applied to continental margins, and in part due to the difficulty of equating chronostratigraphic and biostratigraphic control. The subject sample is believed to be associated with a reefal type of environment situated on the outer shelf associated with the 60 m still-stand of Poag and Sweet (1972). The sample has *G. menardii* present and is probably of Holocene age, although the possibility of it being of latest Wisconsin age should not be overlooked.

Sample Fauna and Flora

The prolific nature of the foraminifera in mudlump samples is attested to by the publications of Andersen (1961) and Andersen *in* Morgan *et al.* (1963). In the 1961 publication Andersen described 213 species and 8 subspecies and in 1963 added another 21 species.

A 25 ml sample was selected for examination. Of this, approximately 20 ml remained on the +30 (>600 μ) mesh. This material was composed of mollusk debris, oyster fragments, gastropods, echinoid spines, echinoid plates, bryozoa, worm tubes, otoliths, crustacean debris, fish bones, plus large representatives of some of the foraminifera described later. The benthic foraminiferal component comprised 12 agglutinated species (9 genera), 121 calcareous benthic species (72 genera) and 11 planktic genera with 24 species were recorded.

In addition, one gram of washed residue was examined to determine the Foraminiferal Number. This is not in strict accordance with the Schott (1935) method but is believed acceptable following the philosophy of Boltovskoy and Wright (1976) who regarded FN simply as a crude index of foraminiferal abundance in an area as variables (ecologic and biologic) affect this measurement. The FN subdivisions as outlined in Boltovskoy and Wright (1976) are followed.

FN_t	= 5722	FN_{cb}	= 2809
FN_b	= 4567	FN_{hb}	= 2119
FN_{ab}	= 1758	FN_{pb}	= 690
	FN_p = 1155		

It is believed that the difference between this method and that of Schott (1935) would be that the above figures would be somewhat high.

Following the concept proposed by Uchio (1960) that if the number of species per genus decreases with depth, the benthic fauna would indicate a bathymetry of 110 meters (index = 1.64). The planktic-benthic ratio would suggest a bathymetry of around 85 meters (Grimsdale and Morkhoven, 1955). The Fisher α value (described in Murray, 1973) gives an approximate α >20 value which would suggest an open marine shelf sea. The Miliolina-Textulariina-Rotaliina triangular plot (Murray, 1973) again indicates a shelf sea environment. The presence of occasional warmer-water, carbonate-loving benthics in the sample corroborates well with the environment postulated earlier (reefal type of association in the outer portions of the continental shelf).

Corroboration of a shelf environment is provided by the ostracod fauna. Ostracod genera present are *Echinocythereis* Puri, *Hulingsina* Puri, *Henryhowella* Puri, *Krithe* Brady, Crosskey and Robertson, *Puriana* Coryell and Fields, *Cytheropteron* Sars, *Pterygocythereis* Blake, *Cytherura* Sars, *Buntonia* Howe, *Aurila* Pokorny, *Cytherella* Jones, *Argilloecia?* Sars, *Munsyella?* van den Bold, *Cativella* Coryell and Fields. This association is indicative of a middle to outer shelf environment (N. J. Tartamella, personal communication, 1977). Howe and van den Bold (1975) suggest a water depth of approximaely 100 feet for ostracod faunas they retrieved from similar mudlump samples.

The indication that the environment suggested by this assemblage has good marine connections is supported by the calcareous nannoflora composed of *Emiliania huxleyi* (Lohmann), *Gephyrocapsa oceanica* Kamptner, *Umbilicosphaera mirabilis* Lohmann, *Scapholithus fossilis* Deflandre, *Helicopontosphaera kamptneri* Hay and Mohler, *Rhabdosphaera clavigera* Murray and Blackman, *Syracosphaera histrica* Kamptner, *Cricolithus jonesi* Cohen, *Thoracosphaera saxea* Stradner, *Cyclococcolithus leptoporus* (Murray and Blackman), and *Umbellosphaera tenuis* Kamptner. The last taxon supports a warm water interpretation for this sample (W. E. Steinkraus and P. E. Koeppel, personal communication, 1977).

In summary, the microfauna and microflora suggest a warm water, open marine, probably outer shelf location for this sample, the assemblage also indicating a reefal or calcareous mound build up somewhat similar to the banks found at the present day in the northern Gulf of Mexico.

IV. ACKNOWLEDGMENTS

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V. SYSTEMATIC DESCRIPTIONS

The retrieval of four additional specimens of *Voorthuyseniella* from the mudlump sample has made it advisable to place forms previously described with open nomenclature into a more stable taxonomic position. The value of these epithets is, of course, dependent upon the biologic nature of the organism. Since, at present, this is unknown, the nomenclature may, with additional knowledge, need to be changed at a future date. Until that time, however, the names proposed herein should provide a more uniform method of communication when compared to the problems inherent with open nomenclature.

Test orientation, morphologic terms and measurement teminology used in this report are adapted from Haman and Kohl (1976a,b) and Haman (1978).

VOORTHUYSENIELLA BAILEYI n. sp.

Plate 1, figs. 1-5

Voorthuyseniella sp. indet. HAMAN AND KOHL, 1976, Tulane Stud. Geol. Paleont., vol. 12, no. 3, p. 157, 158, pl. 1, figs. 1-7; pl. 2, figs. 1-4.

Description: Test free, calcareous, imperforate, unilocular, nearly spherical. Test widest at or just below the middle of the camera when viewed from either lateral aperture (pl. 1, figs. 1,3). Test shows symmetrical cameral inflation viewed from above (pl. 1, fig. 4). Tubus reasonably flat to becoming higher on one end (towards lateral aperture "A"). Tubus is widest at the middle, narrowing to either end (pl. 1, fig. 5). Porta is subcircular to ovate (0.09 mm × 0.06 mm) situated in a bevelled depression (0.12 mm × 0.09 mm) at the top of the camera. Tubus pore is subcircular to elliptical (0.06 mm × 0.03 mm), situated midway between the lateral apertures and in line with them. Test twisting or distortion is not evident. Lateral aperture "A" is circular to subcircular with cameral extension over the upper part (pl. 1, figs. 1,2). The thickness of wall rim surrounding the aperture varies from .018 mm-.010 mm. Lateral aper ture "B" is circular in shape surrounded by a fairly flat thick rim (pl. 1, fig. 3) varying in width from 0.031 mm-0.048 mm. No internal septa are present in the camera. Test surface under light microscope examination appears striate but with SEM examination this is shown to be the effect of differential solution. The solution effect does not appear to be restricted to any specific area of the test but is evident over the camera and tubus. The tubus region appears to be more severely affected by the solution effect than the camera.

Test Dimensions: Maximum length 0.35 mm, maximum width 0.31 mm, height 0.27 mm.

Locality: Outcrop sample, mudlump 90, South Pass Area of the Mississippi Delta.

Stratigraphic Level: Early Holocene.

Derivato nominis: The species is named in honor of Mr. J. R. Bailey, technical assistant (Paleontology), Chevron U.S.A., Inc., Eastern Region.

Remarks: The affinities of this species have already been discussed (Haman and Kohl, 1976b) and no purpose is served by repeating the analysis. Specific variation can be noted between the mudlump form and the previously described upper Pleistocene form (Haman and Kohl, 1976b) as follows. The test size has an overall range of length 0.31-0.35 mm, width 0.24-0.31 mm, and height 0.24-0.27 mm. The mudlump specimen is slightly larger but this can be attributed to growth. Porta and tubus shape is variable but essentially very similar and can be attributed in both cases to probable test dissolution. The stratigraphic range of the species is late Pleistocene to early Holocene.

VOORTHUYSENIELLA GREIGI n. sp.
Plate 1, figs. 6-10

Voorthuyseniella sp. 1, HAMAN, 1978, Revue de Micropaléontologie, vol. 20, no. 4, p. 189, pl. 1, figs. 1-7.

Description: Test free, calcareous, imperforate, unilocular, longer than high, as wide as high, asymmetric in side view, tapering from the portal region to both lateral apertures (pl. 1, fig. 7). Test is widest at or just below the middle of the camera when viewed from either lateral aperture (pl. 1, figs. 6, 8). Test exhibits slight asymmetric cameral inflation when viewed from the porta (pl. 1, fig. 9). Test twisting is not evident. Tubus reasonably flat, slightly higher at "A" lateral aperture end (pl. 1, fig. 7). Tubus widest at the middle tapering slightly to either end (*i.e.*, towards the lateral apertures) (pl. 1, fig. 10). Tubus pore is subcircular to elliptical (0.018 × 0.038 mm) situated midway between the lateral apertures and in line with them. Porta is subcircular to ovate in shape (0.045 × 0.030 mm) situated in a bevelled depression (0.10 × 0.08 mm) at the top of the camera. Lateral aperture "A" is subcircular to elliptical in shape with cameral extension over the upper part (pl. 1, figs. 6, 7). The wall rim around lateral aperture "A" varies in thickness from 0.020-0.005 mm. A small, thin, partially eroded, delicate flap is present above the cameral extension (pl. 1, fig. 9). Lateral aperture "B" is circular in shape surrounded by a fairly flat thick rim varying in width from 0.031-0.030 mm (pl. 1, fig. 8). No internal septa are present in the camera. Test surface under light microscope examination appears faintly striate but with SEM examination this is seen to be the result of differential solution. The solution effect is present on the camera and tubus, but is more severe on the tubus region.

Test dimensions: Maximum length 0.35 mm, maximum width 0.23 mm, height 0.24 mm.

Locality: Outcrop sample, mudlump 90, South Pass area of the Mississippi Delta.

Stratigraphic level: Early Holocene.

Derivato nominis: The species is named in honor of Mr. D. Greig, technical assistant (SEM operator), Chevron U.S.A., Inc., Eastern Region.

Remarks: The taxonomic affinities of this species and its paleobathymetric distribution have already been discussed (Haman, 1978). Specific variation can be noted between the mudlump form and the previously described late Pleistocene form as follows. The test size has an overall range of width 0.23-0.25 mm, height 0.23-0.24 mm, the length of both forms are identical. The thin delicate flap is better represented in the late Pleistocene form, compared to the Holocene form. This is believed to be simply the result of test erosion as vestigial traces of the flap are present in the mudlump form. The stratigraphic range of the species is late Pleistocene to early Holocene.

VOORTHUYSENIELLA WILLIAMSAE n. sp.
Plate 2, figs. 1-10
Plate 3, figs. 1-3

Voorthuyseniella sp. 2. HAMAN, 1978, Revue de Micropaléontologie, vol. 20, no. 4, p. 191, pl. 2, figs. 1-6.

Description: Test free, calcareous, imperforate, unilocular, as high as long, only slight asymmetry exhibited in side view (pl. 2, figs. 2,7). Camera inflated, globular to subglobular when viewed from either lateral aperture (pl. 2, figs. 1,3,6,8). Camera may be slightly compressed when viewed from the porta (pl. 2, fig. 9) so that a

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PLATE 1
(Bar = 100 microns)

Figures 1-5. *VOORTHUYSENIELLA BAILEYI* n.sp. (Holotype) 87
(1) view to lateral aperture "A", (2) side view, (3) view to lateral aperture "B", (4) portal view, (5) view to tubus and tubus pore.

Figures 6-10. *VOORTHUYSENIELLA GREIGI* n.sp. (Holotype) 88
(6) view to lateral aperture "A", (7) side view, (8) view to lateral aperture "B", (9) portal view, (10) view to tubus and tubus pore.

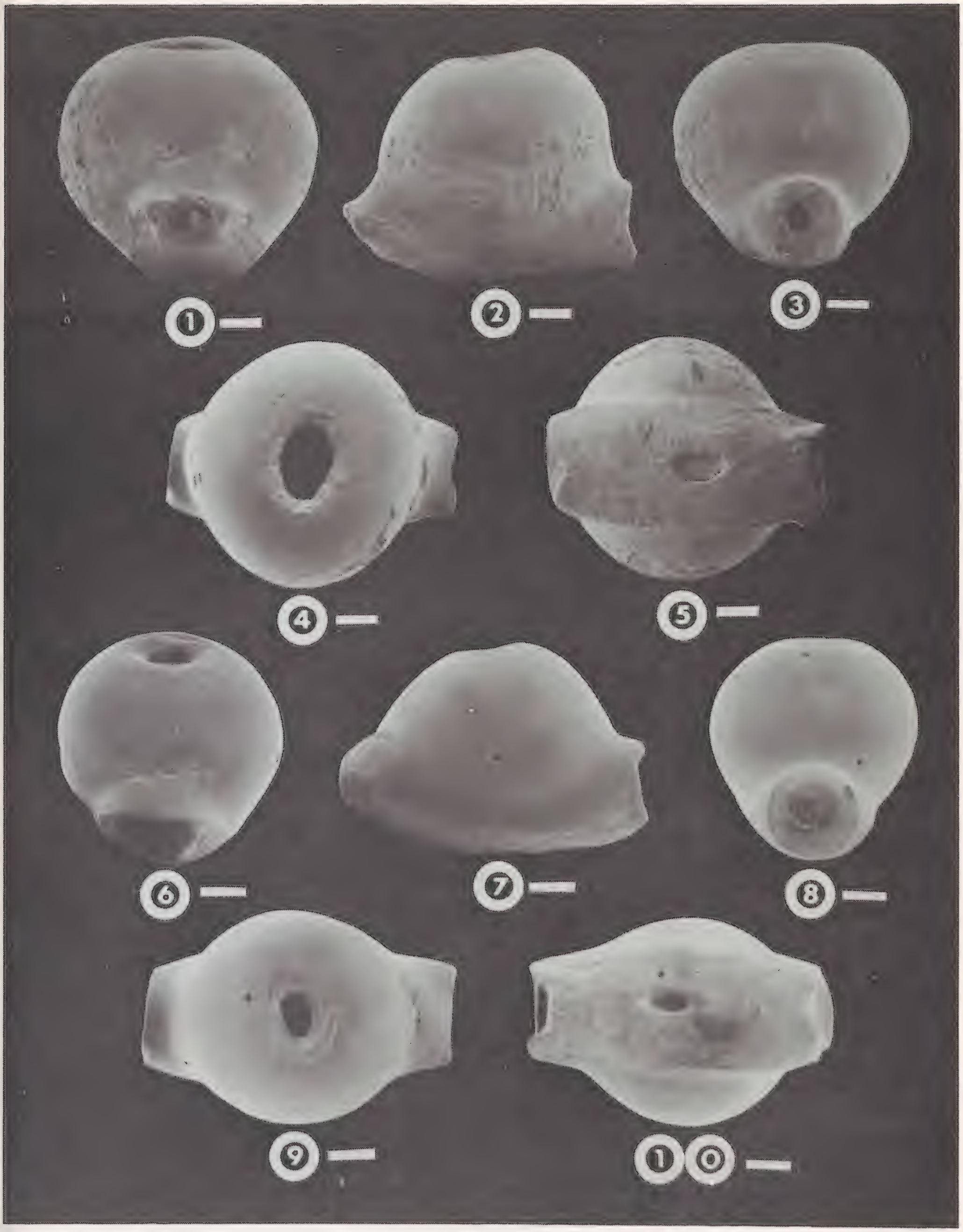

PLATE 1

slightly ovate camera is situated transverse to tubus. This cameral compression is variable and may be minimal (pl. 2, fig. 4). Test is widest at, or just below, the middle of the camera when viewed from either lateral aperture (pl. 2, figs. 1,3,6,8). No test twisting is evident. Tubus is slightly curved in side view, higher at lateral aperture extremities than at the center (pl. 2, figs. 2,7). Tubus surface flat, wider at the end adjacent to lateral aperture "B" tapering to lateral aperture "A" (pl. 2, figs. 5,10). Degree of tapering is variable. Tubus pore ovate to elliptical, situated midway between the lateral apertures and in line with them. Tubus pore may be set in a slight depression. Porta, ovate to elliptical in shape, situated in a bevelled depression at the top of the camera, and orientated transverse to the tubus (pl. 2 figs. 4,9). Lateral "A" is subcircular in shape with an extension of the camera over the upper portion (pl. 2, fig. 1,6). A thin delicate flap is present above this cameral extension (pl. 2, figs. 6,9) although it may be eroded (pl. 2, figs. 1,4). Lateral aperture "B" is subcircular in shape surrounded by a thick rim (pl. 2, fig. 3). No cameral septa are evident. Test surface appears to be delicately striate under light microscope examination but SEM analysis shows this to be the result of solution effects. The solution effects are present over both the camera and tubus, but are most noticeable over the tubus.

Test dimensions: Maximum length 0.32 mm, maximum width 0.30 mm, height 0.30 mm.

Locality: Outcrop sample, mudlump 90, South Pass area of the Mississippi Delta.

Stratigraphic Level: Early Holocene.

Derivato nominis: The species is named in honor of Ms. C. F. Williams, Paleontologist, Chevron U.S.A., Inc., Eastern Region.

Remarks: These two specimens, along with the one previously described, illustrate a number of variable morphologic features, all of which are believed to represent acceptable specific variation. This variation is discussed below. The degree of asymmetry exhibited by the test in side view is minimal (pl. 2, fig. 2) to more pronounced (Haman, 1978, pl. 2, fig. 2). The amount of cameral compression varies from minimal (pl. 2, fig. 4) to noticeable (Haman, 1978, pl. 2, fig. 6). The rapidity of tubus tapering from adjacent to lateral aperture "B" to lateral aperture "A" varies between specimens, from gentle (Haman, 1978, pl. 2, fig. 5) to severe (pl. 2, fig. 10). The tubus pore shape is variable, ranging from subcircular (pl. 2, fig. 10) to elongate (Haman, 1978, pl. 2, fig. 5). Variable measurements of various features between the specimens as noted in Table 1.

Table 1

	Specimen 1 (pl. 2, figs. 1-5)	Specimen 2 (pl. 2, figs. 6-10)	Specimen 3 (1978, pl. 2, figs. 1-6)
Max. length	0.32 mm	0.28 mm	0.37 mm
Max. width	0.30 mm	0.26 mm	0.28 mm
Max. height	0.30 mm	0.28 mm	0.31 mm
Porta	0.060 × 0.091 mm	0.030 × 0.070 mm	0.040 × 0.085 mm
Tubus pore	0.035 × 0.065 mm	0.031 × 0.045 mm	0.040 × 0.140 mm

This variation is believed related to the growth process of the organism and with the case of certain features to solution effects.

Close examination of the specimen illustrated on plate 2, figures 6, 9, shows a rectangular feature on the test adjacent to the porta. An enlargement of this specimen

PLATE 2
(Bar = 100 microns)
VOORTHUYSENIELLA WILLIAMSAE n. sp.

Figures 1-5. Holotype 88
(1) view to lateral aperture "A", (2) side view, (3) view to lateral aperture "B", (4) portal view, (5) view to tubus and tubus pore.

Figures 6-10. Paratype
(6) view to lateral aperture "A", (7) side view, (8) view to lateral aperture "B", (9) portal view (note crystal scar indicated by arrow), (10) view to tubus and tubus pore.

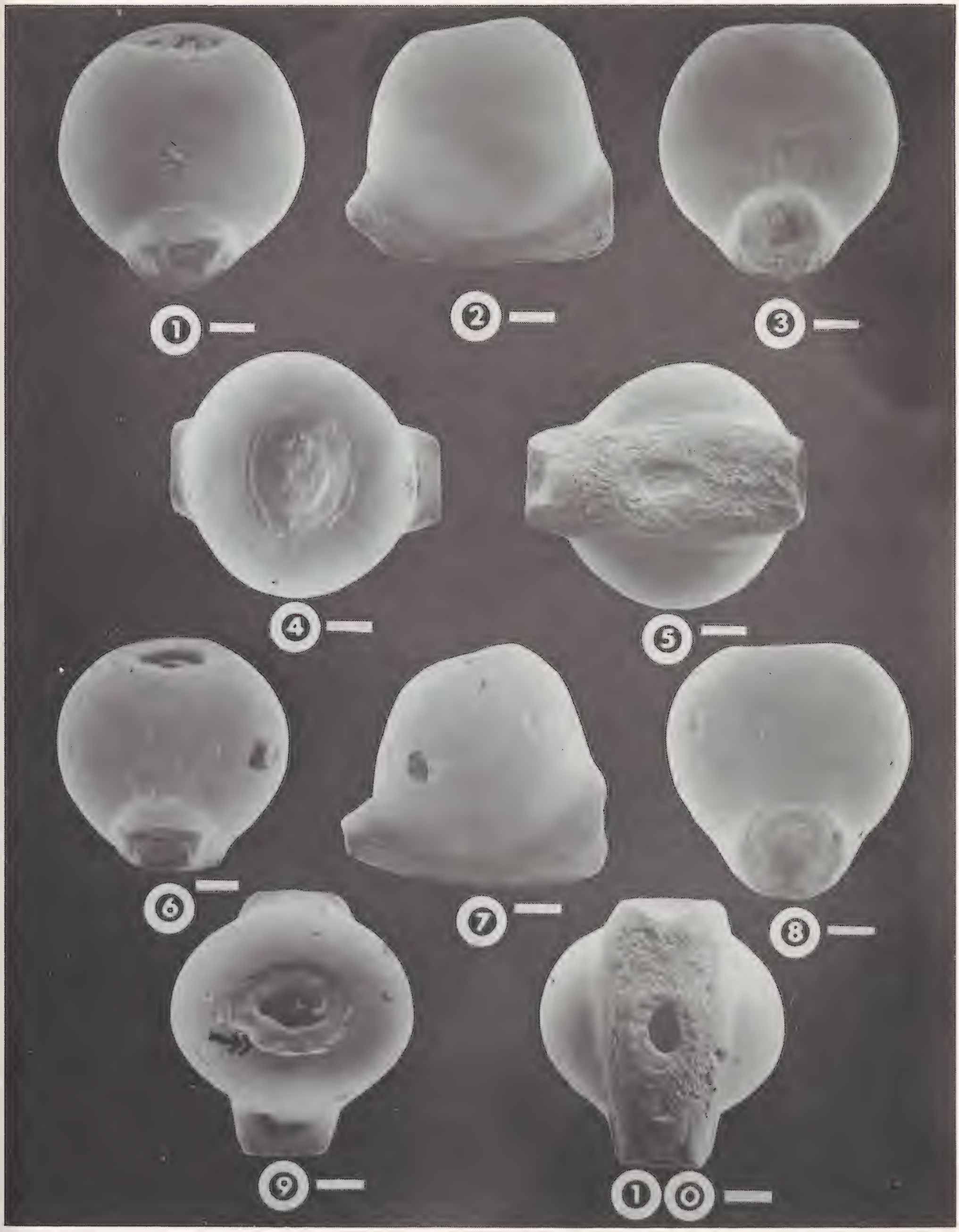

PLATE 2

(pl. 3, fig. 1) and of the relevant area (pl. 3, figs. 2,3) demonstrates that the feature is real. The "scar" is believed to have resulted from crystal overgrowth on the test. Later crystal removal leaves the scar. Crystal overgrowths are not unknown on foraminifera and there does not appear to be any reason why they could not occur on problematic organisms. Akers, 1979, illustrated *Globigerina* sp. (pl 19, fig. 2) from the Neogene of Mexico that has distinct pyrite crystals developed in the apertural region. Towe *et al.* (1977, pl. 1, fig. 1) document secondary calcite rhombs on tests of *Patellina corrugata* Williamson. These laboratory-created rhombs could occur in the natural state and would, if removed from the test, leave scars identical to the one displayed on the specimen of *V. williamsae*. The stratigraphic range of the species is late Pleistocene to early Holocene.

VI. APPENDIX.
List of species from sample

Due to the rapidly changing nomenclature of the foraminifera on a supraspecific level, the taxa obtained from the mudlumps sample are listed below by group, and alphabetically by species. As the systematic evaluation of the generic assignments was not the purpose of this article, the majority of the generic names remain as those familiar to Gulf Coast paleontologists.

AGGLUTINATED BENTHIC SPECIES

aequa, cf., *Gaudryina* Cushman
affinis, *Siphotextularia* (Fornasini)
barrettii, *Textulariella* (Jones and Parker)
calva, *Textularia* Lalicker
irregularis, *Bigenerina* Phleger and Parker
mayori, *Textularia* Cushman
mexicana, *Clavulina* Cushman
mexicana, *Textularia* Cushman
parkerae, *Cribrobigenerina* Andersen
parva, *Psammosphaera* Flint
sica, *Textularia* Lalicker and Bermudez
soldanii, *Liebusella* (Jones and Parker)

CALCAREOUS BENTHIC SPECIES

advena, *Rectobolivina* (Cushman)
albatrossi, *Bolivina* Cushman
albatrossi, *Nodosaria* Cushman
ampla, *Saracenaria* Cushman and Todd
antillarum, *Neoeponides* (d'Orbigny)
antillarum, *Spiroloculina* d'Orbigny
atlantica, *Nodobacullariella* Cushman and Hanzawa
atlanticus, *Florilus* (Cushman)
atlanticus, *Tretomphalus* Cushman
barbata, *Brizalina* (Phleger and Parker)
barleeanus, *Melonis* (Williamson)
basiloba, *Nonionella* Cushman and McCulloch
beccarii, *Ammonia* (Linne)
bella, *Trifarina* (Phleger and Parker)
bellula, *Uvigerina* Bandy
bertheloti, *Discopulvinulinella* (d'Orbigny)
bicostata, *Quinqueloculina* d'Orbigny
bowdenensis, *Lenticulina* (Cushman)
bulloides, *Sphaeroidina* d'Orbigny
calcar, *Lenticulina* (Linne)
camachoi, *Amphicoryna* Andersen
candeina, *Rosalina* (d'Orbigny)
carinata, *Pyrgo* (d'Orbigny)
cassis, *Nodobacullariella* (d'Orbigny)
caudigera, *Oolina* (Wiesner)
communis, *Dentalina* d'Orbigny
compta, *Quinqueloculina* Cushman
concentrica, *Hanzawaia* (Cushman)
concentrica, *Stomatorbina* (Parker and Jones)
dentata, *Spiroloculina* Cushman and Todd
discoidale, *Elphidium* (d'Orbigny)
elegans, *Hoeglundina* (d'Orbigny)
falcifer, *Lenticulina* (Stache)
faveolata, *Planulina* (Brady)
filiformis, *Dentalina* (d'Orbigny)
fimbriatulum, *Elphidium* (Cushman)
flintii, *Sigmoilopsis* (Cushman)
floridanus, *Cibicides* (Cushman)

PLATE 3

VOORTHUYSENIELLA WILLIAMSAE n.sp.

Figures 1-3. Paratype 88

(1.) Portal view with crystal scar indicated by arrow No. 1 (×270).

(2.) Enlargement of portion of Figure 1 to show scar margin (indicated by white lines). Area of enlargement illustrated on figure 1 by arrow No. 2 (×2600).

(3.) Enlargement of portion of Figure 2 to show scar margin (indicated by white lines). Area of enlargement illustrated on Figure 2 by arrow (×13,000).

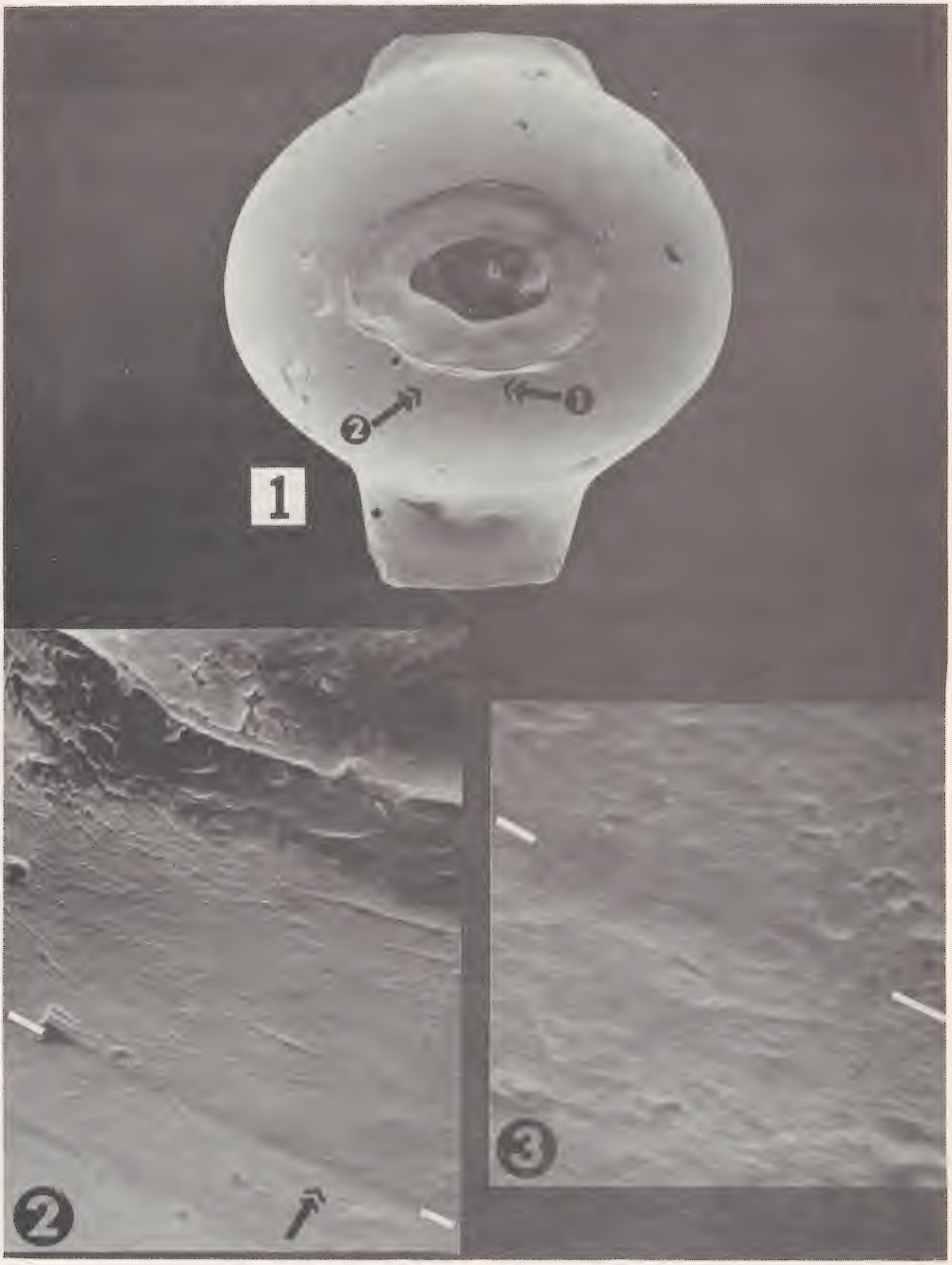

PLATE 3

floridensis, *Rosalina* (Cushman)
fragilis, *Brizalina* (Phleger and Parker)
fusta, *Nodosaria* Cushman and Todd
garettii, *Quinqueloculina* Andersen
gelbi, *Loxostomum* Andersen
gibbosa, *Amphistegina* d'Orbigny
globulifera, *Ramulina* Brady
globulus, *Sphaerogypsina* (Reuss)
grateloupi, *Florilus* (d'Orbigny)
gunteri, *Elphidium* Cole
hannai, *Buccella* (Phleger and Parker)
hexagona, *Oolina* (Williamson)
hispidula, *Lagena* Cushman
incertum, *Elphidium* (Williamson)
insignis, *Triloculina* (Brady)
inusitata, *Lagena* Andersen
io, *Cibicidoides* (Cushman)
iotus, *Lenticulina* (Cushman)
labiosa, *Miliolinella* (d'Orbigny)
laevigata, *Glandulina* (d'Orbigny)
laevis, *Lagena* (Montagu)
lateralis, *Poroeponides* (Terquem)
latiformis jamaicensis, *Saracenaria* Cushman and Todd
lessonii, *Amphistegina* d'Orbigny
marginata, *Bulimina* d'Orbigny
marginata, *Fissurina* Seguenza
mayori, *Articulina* Cushman
mediterranensis, *Planorbulina* d'Orbigny
melo, *Oolina* d'Orbigny
mera, *Planulina* Cushman
mexicana, *Cassidulinoides* (Cushman)
mexicana, *Valvulineria* Parker
miocenica, *Pavonina* Cushman
miocenica, *Reussella* Cushman
nasuta, *Pyrgo* Cushman
nucleatus, *Anomalinoides* (Seguenza)
occidentalis, *Trifarina* (Cushman)
orbitolitoides, *Broeckina* (Hofker)
parkinsoniana, *Ammonia*, (d'Orbigny)
parvula, *Eouvigerina* Cushman
pauciloculata, *Ammonia* (Phleger and Parker)
perprocera, *Marginulina* (Schwager)
planata, *Vaginulinopsis* (Phleger and Parker)
pontoni, *Fursenkoina* (Cushman)
popei, *Chrysalidinella* Andersen
proteus, *Peneroplis* d'Orbigny
pulchra, *Siphonina* Cushman
punctata, *Fursenkoina* (d'Orbigny)
pyrula, *Nodosaria* d'Orbigny
roederi, *Amphicoryna* Andersen
sabulosa, *Quinqueloculina* Cushman
saggitula, *Frondicularia* van den Broeck
sagra, *Cancris* (d'Orbigny)
schlumbergeri, *Sigmoilina* Silvestri
selseyense, *Uvigerina* Heron-Allen and Earland
sp. *Cushmanella*
sp. B., *Fissurina* (of Akers and Dorman, 1964)
sp. formae fistulosae, *Globulina*
spicaeformis, *Guttulina* (Roemer)
spicata, *Lagena* Cushman and McCulloch
spinata, *Brizalina* (Cushman)
spirata, *Lagena* Bandy
spp. Elphidium
spp. *Lenticulina*
spp. *Vaginulinopsis*
strattoni, *Hanzawaia* (Applin)
striatula, *Marginulina* Cushman
subcarinata, *Pullenia* (d'Orbigny)
subglobosa, *Cassidulina* Brady
substriata, *Lagena* Williamson
suezensis, *Rosalina* (Said)
tenuis, *Bulimina* Phleger and Parker
tepida, *Ammonia* (Cushman)
terquemi, *Neoconorbina* (Rzehak)
toddae, *Biloculinella* Andersen
tricarinata, *Triloculina* d'Orbigny
trigonula, *Triloculina* (Lamarck)
tumidulus, *Neoeponides* (Brady)
vespertilio, *Pyrgo* (Schlumberger)
vivipara, *Spirillina* Ehrenberg
westi, *Oridorsalis* Andersen

PLANKTIC SPECIES

aequilateralis, *Hastigerina* (Brady)
bulloides, *Globigerina* d'Orbigny
conglobatus, *Globigerinoides* (Brady)
dehiscens, *Sphaeroidinella* (Parker and Jones)
dutertrei, *Neogloboquadrina* (d'Orbigny)
eggeri, *Neogloboquadrina* (Rhumbler)
falconensis, *Globigerina* Blow
fimbriata, *Globorotalia* (Brady)
finalis, *Pulleniatina* Banner and Blow
glutinata, *Globigerinita* (Egger)
helicina, *Globigerinoides* (d'Orbigny)
hirsuta, *Globorotalia* (d'Orbigny)
inflata, *Turborotalia* (d'Orbigny)
menardii, *Globorotalia* (d'Orbigny)
nitida, *Candeina* (d'Orbigny)
pyramidilis, *Globigerinoides* van den Broeck
ruber, *Globigerinoides* (d'Orbigny)
sacculifer, *Globigerinoides* (Brady)
siphonifera, *Hastigerina* (d'Orbigny)
trilobus, *Globigerinoides* (Ruess)
truncatulinoides, *Globorotalia* (d'Orbigny)
tumida, *Globorotalia* (Brady)
ungulata, *Globorotalia* Bermudez
universa, *Orbulina* (d'Orbigny)

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TWO NEW BALANID BARNACLES (CIRRIPEDIA) FROM THE PINECREST SAND OF SARASOTA, FLORIDA

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INTRODUCTION

Two species of barnacles — *Balanus sarasotensis* Weisbord, 1971, and *Balanus newburnensis*, n. sp. — were collected by Harbans Puri in 1970 in what are locally known as the Warren Brothers Pits. These are situated 4.8 miles due east of Washington Boulevard, Sarasota in Sect. 13, T36S, R18E, Sarasota County, Florida. The approximate co-ordinates of the Pits are 27°22′27″N, 82°27′20″W.

The section exposed within the pits was measured and described by Harbans Puri and that section (see Weisbord, 1972, p. 60), with the fossil identifications determined by Puri, is reproduced below.

WARREN BROTHERS PITS —
Sarasota, Fla.

4.5 miles east off U. S. 301, 17th Street, dead end, turn left on paved road [Newburn Rd.], go 0.4 miles, pits on right.

BED	DESCRIPTION	THICKNESS [Ft.]
4	Pleistocene Sand Pinecrest Formation	+15
3	Oyster biostrome, as bed 1 (delicate) *Pecten* sp., *Ostrea haitensis* (Sowerby) mostly articulated valves, *Conus* sp.	4
2	Shell hash, sandy with few complete mollusks; top of the bed marked with *Mytiloconcha* sp. oriented as in life. Can be traced laterally around the pits.	1
1	Oyster biostrome Light gray to green shell hash, quartz sand with *Ostrea haitensis* (Sowerby), *Pecten eboreus darlingtonensis* Dall, *Cancellaria propevenusta* Mansfield, *Murex globosus* Emmons, *Conus adversarius* Conrad.	3

Also in 1970 a detailed study of the Warren Brothers Pits was made by Muriel Hunter of Coastal Petroleum Company, and there is presented below, with Hunter's permission, her composite section, which overlaps that of Puri and continues deeper to the base of the Pinecrest Sand.

COMPOSITE SECTION,
WARREN BROS. NEW PIT
December 15, 1970
M. E. Hunter

Surface beds, north wall, west of pump

BED	DESCRIPTION	THICKNESS [Ft.]
15	Soil, brown	+4
14	Sand, white, loose	+1-2
13	Sand, buff, loose; top wavy and irregular	+4

Maximum total sand and soil about 9 to 10 feet.
Age uncertain.

TAMIAMI FORMATION
(Pinecrest Sand Member)

On south side of pump excavation, in ditch overlain by about 4′ of buff sand and spoil pile:

12	White shell hash, includes many small shells of ½ to 1 inch in size; sandy	½
11	*Pecten* hash, with many *Anadonta alba* or *A. schrammi*; pectens mostly of *P. eborius* type, with a few other specimens of different species	1
10	*Ostrea haitensis* biostrome: Light gray, single and articulate valves; a few other species. Micro-shell-hash at base, and in some places all through bed	3

On north side of pump excavation, beneath pump walk:

10	*Ostrea haitensis* biostrome as on south side, also 3 feet in thickness	
9	Mixed shell in light gray sand. Zone of *Pecten* fragments in spots around pit not usually over 6 inches thick at bottom	3
8	*Ostrea haitensis* biostrome, dark grey	2

There is an irregular contact between beds 7 and 8.

7.	*Vermicularia woodringi* zone. Upright tubes of this species in clusters. Iron seepage starts in this bed. Shapes and occurrence of clusters of *Vermicularia* added to the habit of this genus of living in sponges suggests that this may be a sponge bed.	½-1
6	*Strombus alatus* biostrome. Abundant *Strombus* with a few other species	1
5	Mixed shell in sand	1
4	Mixed shell in sand. Similar to above but contains *Chione ulocyma* and *Sconsia hodgei*. *Vermicularia* (new species?) at base, also horizontal tubes of *Petaloconchus* (not *sculpturatus*). Large black bone fragments at base of bed. The tubes are oriented parallel with bedding and apparently lived that way	½

[There is a possibility of a small hiatus between beds 4 and 3.]

3 Gray clayey sand with weathered crumbly shells, mainly small *Mercenaria* species 2

Bed 3 is probably *Ecphora* Zone equivalent.

2 Phosphatic clayey sand, no fossils seen 3

Beds 2 through 12 equivalent to the Jackson Bluff Formation.

UNCONFORMITY TAMIAMI FORMATION
(Murdock Station Member)

1 Clay, phosphatic, semi-consolidated, with abundant *Pecten jeffersonius* and fragments of Murdock barnacles (Looks like Murdock Station Unit. *Arca* Zone equivalent) 2

The two new barnacles of this report were collected in the oyster biostrome of Puri's Bed 1, one foot below the *Mytiloconcha* sp. horizon of Bed 2. Puri's Bed 1 corresponds in all likelihood with Hunter's *Ostrea haitensis* biostrome of her Bed 10 so that the stratigraphic position of *Balanus sarasotaensis* and *B. newburnensis* in the Warren Brothers Pits, at least, is firmly established. Beds 3 to 1 of Puri and Beds 12 to 2 of Hunter in the Pinecrest Sand are correlated with the Jackson Bluff Formation in Leon County, Florida, the type locality of which is approximately 250 air miles northwest of the pits. The barnacles of the Jackson Bluff Formation have been described by Weisbord (1966) and by Spivey (1977), Spivey noting the occurrence therein of the barnacle *Balanus concavus proteus* Conrad, a form also known from the Tamiami Formation of Florida and the Yorktown Formation of Virginia. These formations (see Hunter, 1968) formerly were considered upper Miocene. However, the Jackson Bluff Formation and the Pinecrest Sand, based on the zonation of planktonic Foraminiferida and on the flora of calcareous nannoplankton (Akers 1972, 1974) are currently considered to be early to middle Pliocene in age and are referred to Zones 19 and 20 of Blow (1969). The age change seems to agree with the reduction in time from about 10 million years duration of the American Pliocene to about 3 million years duration of the European Pliocene, according to the Geologic Time Table compiled by Van Eysinga (1975). Van Eysinga's dating is based on radiometry and geomagnetic events. In any event the Pliocene age of the Pinecrest Sand is accepted by Hunter (personal communication), and there is some supporting evidence in the nature of the corals of the Jackson Bluff Formation (Weisbord, 1971a) and of the barnacle *Creusia neogenica* Weisbord (1972), which was recovered in the same Pinecrest Sand bed as the barnacles *Balanus sarasotaensis* and *Balanus newburnensis* of the present paper.

Since the ages variously assigned to the Pinecrest Formation in the Warren Brothers Pits have been late Miocene, Pliocene, and Pleistocene, Shaak and Nicol (1974) refrained from making a precise placement and age determination of their new bivalve *Plicatula hunterae*, the type locality of which is the Pinecrest Formation in the Warren Brothers Pits. Although the exact bed is not known, it is, according to Hunter, within the Pinecrest Sand interval and is therefore presumed to be Pliocene.

Thus far I have seen no barnacles from the Pinecrest Formation at Sarasota which I have been able to identify in the Jackson Bluff Formation of north Florida. However, I believe some *bleached white* specimens of *Balanus newburnensis* do occur on the Caloosahatchee River, 2-5 miles west of La Belle, Hendry County in what may be the Ayers Landing Member of the Caloosahatchee Formation, as well as a single specimen therein of *Balanus talquinensis* Weisbord, first described from the Jackson Bluff Formation. Hence there is little reason to doubt that of the many hundreds of species yet to be identified in the Pliocene Pinecrest Sand some will have ranged upward from the Miocene, some will be found ranging into the Pleistocene, and that about a third of all Pinecrest molluscan fossils will have survived to Recent time.

ACKNOWLEDGMENTS

I wish to thank Harbans S. Puri and Muriel E. Hunter for their important stratigraphic tables and Emily H. Vokes of Tulane University for her careful review and editorial supervision of this paper. The photographic work was done by Gerritt Mulders of Tallahassee and Alan Brown, Florida State University.

DESCRIPTION OF SPECIES

Class CIRRIPEDIA Burmeister 1834
Suborder BALANOMORPHA Pilsbry 1916
Family BALANIDAE Leach 1817

BALANUS SARASOTAENSIS Weisbord
Plate 1, figs. 1-11

Balanus sarasotaensis Weisbord, 1971, Florida Acad. Sci., Quart. Jour., v. 34, no. 2, p. 101-106, figs. 1-8.

The original description of *B. sarasotaensis* in 1971 was based on individual compartments and a single well preserved shell (SP-2a1, the holotype) within which no opercular valves were recovered. Since then a few more wholly articulated shells as well as separated compartments have been obtained from samples of the Pinecrest Sand from the same Sarasota locality and bed as the holotype. One of the later-recovered shells (SP-2a2) is here figured (pl. 1, figs. 4-7). Additionally a few discrete opercular valves were found in some of the shells as well as loose in the washed sand. With this additional material at hand the original description of *B. sarasotaensis* may be supplemented as follows:

Shell. The largest shell in the collection is 19.5 mm in height at the rostrum, 14.5 mm in rostro-carinal diameter at the base, and 13.5 mm in width at the base between the lateral compartments. With increase in size, the compartments, particularly the rostra, appear humpbacked by virtue of added layers of carbonate.

The new shell (SP-2a2) is 9 mm in height at the carinal end, 11.6 mm at the rostral end; the diameters of the basis are 11.7 mm × 10.2 mm; and the diameters of the orifices are about 5.5 mm × 3.5 mm.

The color of the shells is a light tan, and the outer surface is gnarly and concentrically lineated. Many of the shells are misshapen due to crowded growth conditions.

Opercular valves. The tergum as exemplified in part by SP-2a4 is thin, moderately embayed at the base of the carinal side, and has a long gently concave scutal margin, an evenly convex carinal margin, a sharp apex, and a relatively short spur truncated (by breakage?) at its base. The length from the apex to the base of the spur is 4.5 mm, the width across the base 4.0 mm.

The outer surface of the tergal valve is nearly flat except along the scutal side where there is a narrow convexity of rise extending from the apex to base, there measuring some 0.5 mm in width. This scutal wedge is separated from the carinal surface by a faintly incised spur furrow, and is sculptured by an estimated 25 chevron-like or sinuous folds. The rest of the exterior and much broader side is marked by faint concentric fillets following the contour of the basal margin of the tergum.

In the interior of the tergum, the apical region consists of about seven sharp, elevated, caret-like ridges. The articular furrow (which is the under side of the scutal wedge) is moderately deep, the widest part just below the abrupt bend of the articular ridge. The outer rim of the furrow is slightly curved, and in the lower half, is inclined a litle toward the furrow. The articular ridge is acute and runs obliquely from the apex about a third of the distance to the base where it turns abruptly to parallel the scutal margin, then diminishes to play out before reaching the base of the spur. The crests for the depressor muscle, of which there are six, are laminar and lean toward the interior. The crests project slightly below the basal margin. The spur is short and there may be a small re-entrant between it and the base of the articular furrow.

The scutum of *B. sarasotaensis* is thin, inequilaterally triangular, acute at the basioccludent angle, gently rounded at the basitergal angle, and nearly straight at the base. The scutum of SP-2a6 is 5.7 mm in length from the apex to the basioccludent angle, 4.0 mm in width across the base, and 3.5 mm in length along the tergal margin. The exterior of the scutal valve is flattish except for a general barely perceptible apico-basal depression and a very narrow slope along the tergal margin. The exterior of the scutal valve is sculptured by longitudinal rays or striae and by flattish concentric riblets separated by incised interspaces, the riblets tending to be shingle-like toward the base. The longitudinal radii cover most of the surface but are absent near the occludent margin; where they intercept the concentric riblets, minute longitudinal nodulations are formed. On specimen SP-2a6 there are approximately 26 concentric riblets and these merge to form about 13 teeth in a length of 5.5 mm along the occludent margin. On the narrow slope of the tergal margin the concentric riblets narrow considerably to form the same number of oblique compressed striae.

In the interior of the scutum of SP-2a6 the lateral depressor pit is subquadrate in outline and deeply sunken. The adductor ridge is prominent and straight above; at about the middle of its course it forms an elbow with the lower part of the ridge, which plays out before the base and slants into the adductor furrow; the adductor furrow is about 1.0 mm in width and is moderately shallow. Adjacent to the elbow of the adductor ridge is a triangular depression separated from the lateral depressor pit. Between the upper part of the adductor ridge and the articular ridge is a furrow terminating at the upper end of the lateral depressor pit. The upper part of the articular ridge is ear-like and erect but is flattened below the middle, the flattened segment ornamented with nine or ten oblique plications.

Comparison. Quite unlike the shell, which is distinct, the opercular valves of *Balanus sarasotaensis* invite comparison with those of *Balanus eburneus* Gould. The exterior of the scutum is similar in both species, but in the interior of the scutum the lateral depressor pit of *B. sarasotaensis* is sub-

quadrate and much more deeply sunken than in *B. eburneus*. Further differences are noted in the tergum of *B. sarasotaensis*, which has a narrower and shorter prolongation of the spur and a considerably less embayed basal margin on both sides of the spur than in *B. eburneus*, "which when fully developed has a three-pronged outline" (Pilsbry, 1916, p. 81). I have compared the fossil *B. sarasotaensis* with scores of Recent specimens of *B. eburneus* from Alligator Point, Franklin County, Florida, and without exception the shells of *B. eburneus* are white and smooth contrasted with the gnarled, concentrically lineated surface of the shells of *B. sarasotaensis*.

In my original comments on *B. sarasotaensis* I stated that the "type and only specimen was recovered from loose sand adherent to some large corals." The particular coral was the holotype of *Oculina sarasotana* Weisbord (1971a, pp. 55-57, pl. 13, figs. 2-4), collected by Puri one foot below the *Mytiloconcha* layer in the oyster biostrome of Bed 1. *Oculina sarasotana* has also been identified in the Jackson Bluff Formation at Jackson Bluff, Leon County, Florida and is another of a number of species occurring in both the Pinecrest and Jackson Bluff Formations.

BALANUS NEWBURNENSIS Weisbord, n.sp.
Plate 2, figs. 1-14

This species is characterized by color in the sense that the shell, numerous disarticulated plates, and the opercula are blackish to gray-black in color. The specimens were found loose in the sand of the same bed in the Warren Brothers Pits that contains *Balanus sarasotaensis* Weisbord.

Shell. The shell of *Balanus newburnensis* is relatively short, tubulo-conic, and a little longer than wide, with the broad rostrum convex in profile, and the carina slightly concave in profile. The apex of the rostrum is arched over the orifice whereas that of the angulate carina is erect and leans slightly outward. The orifice is subtrigonal in outline, with the rostral end truncate, and the carinal end attenuated. The length of the orifice is a little over half the width. The peritreme, by virtue of the acute apices and sloping summits of the radii and alae, is saw-toothed. The parietes are sharply triangular, and on the exterior are unctuous and marked by thin faint rugae which are oblique, transverse, or concentric. The radii are triangular, narrowing acutely at the basis; the summits are faintly denticulate and inclined about 45° with respect to the horizontal. The radii are marked by faint narrow horizontal fillets, each terminating at the summit and along the sutural edge in a denticle. The alae are thin and their summits also inclined. The basis is thin and calcareous, the surface marked by concentric lineations, perhaps 25 to 30, becoming more closely spaced toward the off-centered locus of attachment. The larger lineations are interspaced by finer concentric striae. The holotype (SP-3a1) is 11 mm × 10 mm in diameter at the base, 11.8 mm × 4.0 mm at the orifice, and is 9.7 mm in height at the carina and 12 mm at the rostrum.

The sheath occupies one-third to about three-fifths of the interior of the compartments and is generally adherent except at the lower margin, which is smooth and excavated underneath. The upper part of the sheath is sculptured by thin concentric laminae. On the acutely angulated carina the sheath is flexuous, and unlike in other compartments is attached at its lower margin but non-adherent on the lower sides. The lower fifth of the carinal sheath is smooth, the upper four-fifths marked by sharp individual laminae of which there are 20 or so on specimen SP-3a5. The laminae are close together at the apex of the sheath but become successively farther apart toward the smooth area below. The basis attached to the carina on SP-3a5 is thin and calcareous and there are eleven quadrate pores or openings of the longitudinal tubes at the basis junction with

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PLATE 1
Balanus sarasotaensis Weisbord

Figure

1-3. Holotype. Exterior of shell, SP-2a1. Measurements: height at carina 9 mm, at rostrum 6.5 mm; diameters at basis 8.5 mm × 7.6 mm.

4-7. Exterior of shell, SP-2a2. Measurements: height at carina 9 mm, at rostrum 11.6 mm; diameters at basis 11.2 mm × 10.4 mm; diameters of orifice 5.5 mm × 4.5 mm. Fig. 4, lateral view, carina to left. Fig. 5, lateral view, carina to right. Fig. 6, carinal view. Fig. 7, rostral view.

8-11. Opercula. Figs. 8, 9, exterior and interior of tergum (SP-2a4). Measurements: length from apex to base of spur 4.7 mm, width from basiscutal to basicarinal angle 3 mm. Figs. 10, 11, exterior and interior of scutum (SP-2a6). Measurements: length along occludent margin from apex to basioccludent angle 6.3 mm, width across basal margin 4.2 mm.

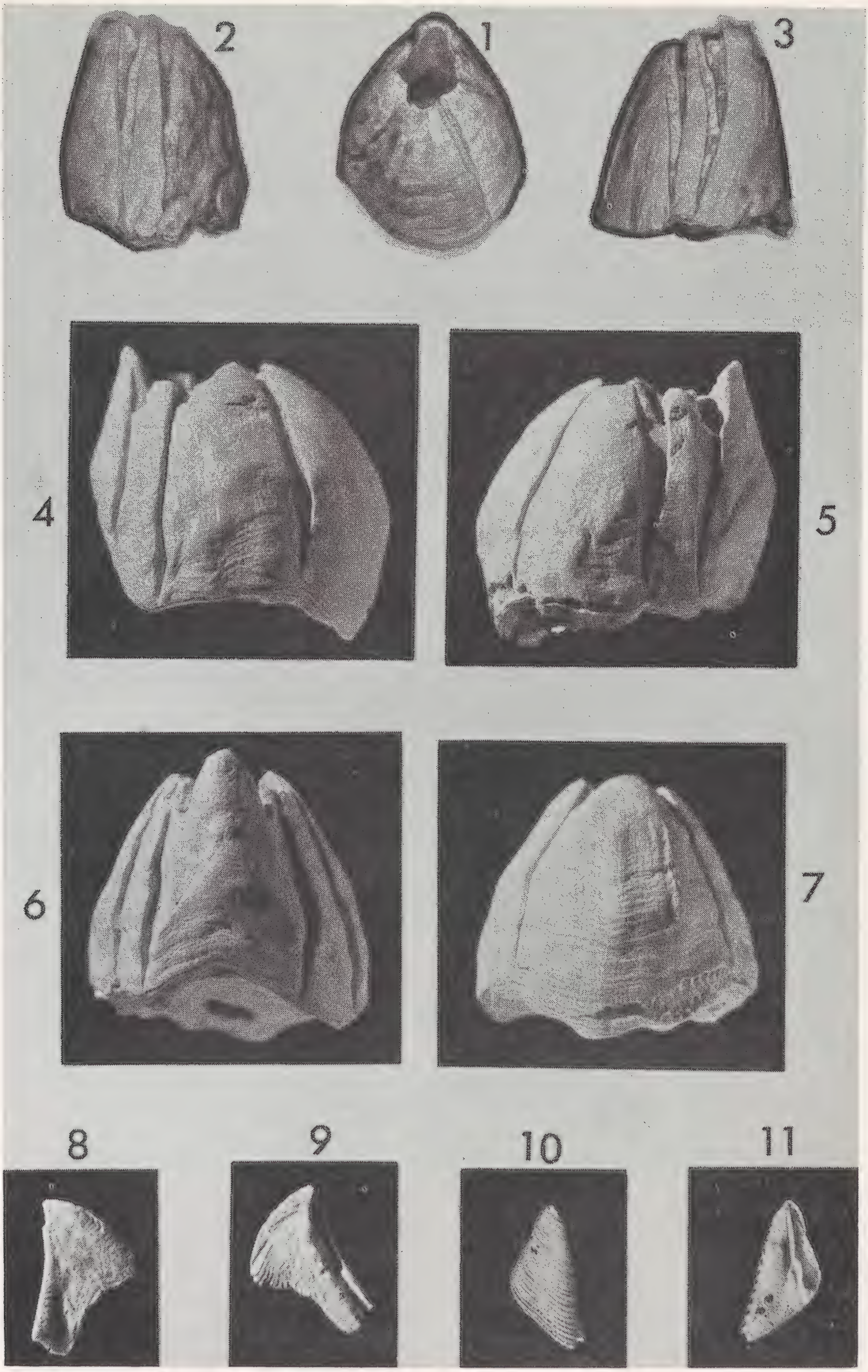

PLATE 1

that of the carinolateral plate. The parietal or longitudinal tubes of the compartment are a little higher than wide near the sheath but broaden below where they become slanted and are marked with auxiliary longitudinal striae at the base. The primary longitudinal septa are sturdy and laminar, each one crested by a longitudinal rib, these ribs most fully developed at the base of the parietes and continuing upward therefrom in diminishing strength to the base of the sheath. Between the primary septa there may be up to four secondary longitudinal septa, these confined to the basal edge of the parietes.

The radii are robust, the upper edge thick and slanting, the sutural edge broad, the later with prominent denticulae. On the sutural edge of specimen SP-3a8, a lateral compartment, there are about 46 primary denticulae in a length of 6.5 mm and about 9 secondary denticulae across the broadest part of the sutural edge (0.7 mm). The alae are thin, small and marked by concentric lineations.

Opercular valves. The scutum, as exemplified by specimen SP-3a3, is 5.8 mm in length along the occludent margin from the apex to the basioccludent angle, and approximately 4.0 mm in width across the basal margin. It is triangular in outline, the sides diverging from the sharp apex at an angle of about 38°. The basioccludent and basitergal angles are narrowly rounded. The basal margin is embayed slightly between the angles, and there is a faint radial depression along the central part of the exterior extending from near the apex to the base. The external surface is sculptured by strong concentric costae, which are smaller and subequal on the apical area, larger and alternating on the basal area. Each costa is thickest at its lower margin and slopes gently toward the costa immediately above it. Throughout, the course of the costae conforms with the contour of the basal margin. All of the costae are raised at the occludent margin at which they bend abruptly upward to produce short oblique ridgelets or denticles on the under side.

In the interior of adult scuta there is a broad apical platform sloping steeply down toward the occludent margin. Below the apex proper there are two diverging prongs, one merging into the adductor ridge, the other into the articular ridge. The occludent side of the prongs is marked by a few vermicular corrugations, and continuing around the apex there are several raised laminae extending down the occludent margin on one side and into the articular furrow of the other. The adductor ridge is slightly curved and forms the crest of a slope on which the large adductor muscle seems to have been located. The upper part of the articular ridge overhangs the narrow articular furrow, on the margins of which are the termini of the concentric costa of the exterior. The pit for the lateral depressor muscle is small and may be shallow or deep.

The tergum of *B. newburnensis* as exemplified by SP-3a4 is dull gray in color, decidedly oblique in outline, and measures 5.3 mm from the apex to the base of the spur and 4.5 mm across the base between the terminal angles. The external surface is flat and tripartite in structure, rendered so by a faint demarcation line from the apex to the carinal side of the spur and a narrowly channeled spur furrow on the scutal side of the spur. On the carinal side of the spur the base is gently embayed and reflects a very gentle depression of the exterior of the surface from near the apex to the basal margin. The markings of the carinal side consist of faint concentric fillets following the contour of the embayed basal margin. The surface markings of the spur consist of reduced concentric riblets concave upward. The scutal portion of the valve is a slightly raised ridge and is marked by flexuous ribs pointing upward in the open spur furrow and downward on the crest of scutal ridge.

PLATE 2

Balanus newburnensis Weisbord, n. sp.

Figure

1-6. Holotype. Exterior of shell, SP-3a1. Measurements: height at carina 9.7 mm, at rostrum 12 mm; diameters at basis 11 mm × 10 mm; diameters of orifice 11.8 mm × 4 mm. Fig. 1, lateral view showing part of basis, carina to left. Fig. 2, lateral view, carina to right. Fig. 3, view of orifice from above. Fig. 4, basis, upper margin toward carina. Fig. 5, frontal (carinal) view. Fig. 6, rostral view.

7-10. Compartments. Interior views of disarticulated specimens. Fig. 7 (SP-3a7), carinolateral compartment, height 5.6 mm, width at wings 2.9 mm. Fig. 8 (SP-3a8), lateral compartment, height 9 mm, width at base 7.6 mm. Fig. 9 (SP-3a5), carina, height 5.9 mm, width at base 3.7 mm. Fig. 10 (SP-3a6), rostrum, maximum height 13 mm, minimum 5.4 mm, width approximately 4 mm.

11-14. Opercula. Figs. 11, 12, exterior and interior of tergum (SP-3a4), length from apex to base of spur 5.3 mm, width across base 4.5 mm. Figs. 13, 14, exterior and interior of scutum (SP-3a3), length along occludent margin from apex to basioccludent angle 5.8 mm, width across basal margin 4.0 mm.

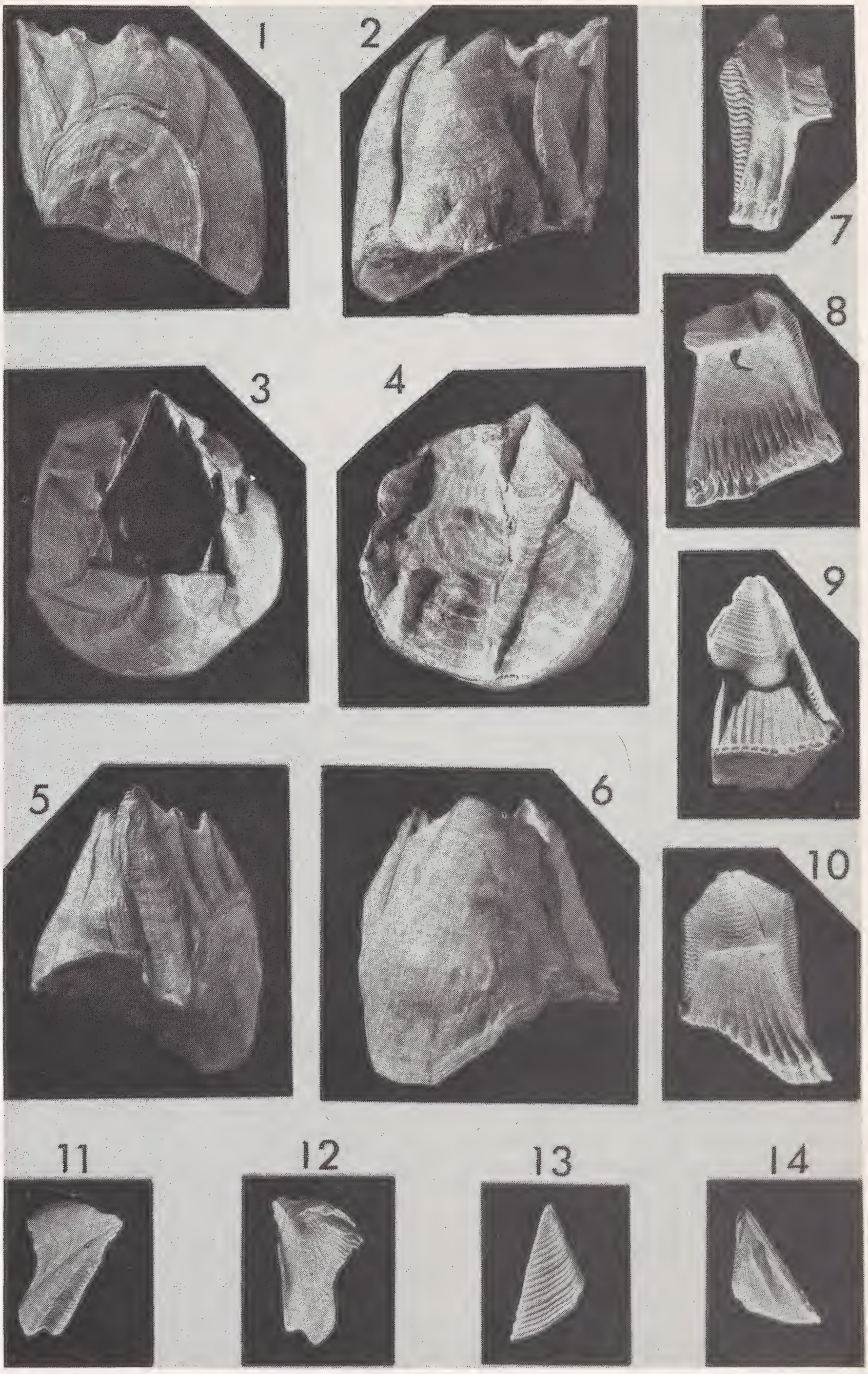

PLATE 2

In the interior of the tergum of *B. newburnensis* the scutal furrow is relatively deep near the apex but shallows and gradually broadens to the base. The articular ridge is high at the apex but becomes less pronounced below. The apex is ornamented on mature specimens by about five acrcuate ridges between which are fine striae. There are six depressor muscle crests represented by six laminae leaning toward the center of the valve, and this central area is roughened by somewhat vermicular, longitudinally interrupted striae. The base of the spur is subangular and between it and the base of the articular furrow there is a re-entrant.

Comparisons. This species seems to fall within the *Balanus amphitrite* complex of Henry and McLaughlin (1975) and is not dissimilar to the Recent *Balanus amphitrite venustus* Darwin which occurs along the coasts of Florida. However, as shown on Henry and McLaughlin's plate 21, figures a-f, there are sufficient minor differences of the shell and opercula between our fossil and the living *B. venustus* that I am persuaded to propose the new species name of *Balanus newburnensis* for the fossil.

It is interesting to note that Darwin's *B. amphitrite obscurus* has been synoymized with *B. a. venustus* by Henry and McLaughlin (p. 8), and that the coloration of the living *B. a. obscurus* was slaty or with "dark slate-colored stripes" (Darwin, 1854, p. 241). It is thus likely that the blackish to gray-black color of our *B. newburnensis* is much the same as it was during its life in the Pliocene. Nevertheless, black shells can become bleached under fossilization as witnessed by the whitish specimens of what I think must be *B. newburnensis* in the Caloosahatchee Formation 2-5 miles west of La Belle, Hendry County, Florida.

Newman and Ross (1976, p. 65) refer to *Balanus venustus* as *Balanus venustus venustus* Darwin.

REPOSITORY

The types and figured specimens of *Balanus newburnensis* and *Balanus sarasotaensis* are conserved at present in the Department of Geology, Florida State University, Tallahassee, Florida 32306, U.S.A.

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October 28, 1981

OLIVINAE (MOLLUSCA:GASTROPODA) FROM THE ALUM BLUFF GROUP OF NORTHWESTERN FLORIDA

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I. ABSTRACT

The subfamily Olivinae encompasses six species and one subspecies in the Alum Bluff Group (lower to middle Miocene) of northwestern Florida. Of these, three species and one subspecies previously described are reviewed. The subspecies is raised to specific rank, and two of the three species receive a new subgeneric or generic assignment. Two new species are described: *Oliva blowi*, from the Chipola and Oak Grove faunas, and *Oliva vokesorum*, from the Chipola only. A new subspecies, *Oliva waltoniana calhounensis*, is named from the Chipola and Oak Grove units. Thus, there is a total of five species of *Oliva* in the Chipola Formation, four of which also occur in the Oak Grove Sand. One species of *Oliva* is confined to the Shoal River Formation, and one specimen of a second species has been collected there. The genus *Jaspidella* is limited to a single species in the Chipola Formation.

II. INTRODUCTION

Only two species of *Oliva* from the Alum Bluff Group of northwestern Florida were included by Dall in his monumental work on the Tertiary fossils of Florida and adjacent areas. The two forms, *O. liodes* and *O. (Omogymna) martensii*, were figured (1903, pl. 58, figs. 1 and 4) and listed in his faunal list (*ibid.*, p. 1576) but were not described. Later, Gardner (1937) described Dall's two species and added a new subspecies of *O. liodes* from the Shoal River Formation, *O. liodes waltoniana*.

More recent collections have provided an abundance of olivid specimens for study, particularly from the Chipola Formation. The author had over 4600 specimens available (Chipola-4515, Oak Grove-7, Shoal River-167), as compared to 390 specimens for Gardner (Chipola-28, Oak Grove-21, Shoal River-341). Gardner's greater percentage of specimens from the Shoal River Formation and the Oak Grove Sand (which is probably a facies of the Chipola Formation) was due in part to her collections from many localities that have eluded subsequent workers.

Dall and Gardner failed to notice, on their specimens of *O. liodes*, the minute depressed posterior band that is characteristic of the subgenus *Omogymna*. Other specimens of this species often show a slightly wider band (± 1.2 mm), which occasionally is visible to the unaided eye. *Oliva*

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(Omogymna) martensii is another member of this subgenus in the Alum Bluff Group. The Chipola and Oak Grove faunas represent the only known occurrence for the presence of two species of *Omogymna* in the western Atlantic. *Oliva liodes waltoniana* is here raised to specific rank due to different subgeneric assignments for *O. liodes* and *O. waltoniana*. *Olivella cofacorys* Gardner was recognized by Olsson (1956, p. 212) to be a member of the Olivinae genus *Jaspidella*.

The subfamily Olivinae apparently evolved from *Agaronia*-like forms during the Jacksonian-Vicksburgian Stages (upper Eocene-middle Oligocene), first as the genus *Strephonella.** *Oliva* s.s. and *Omogymna* made their first appearance in the late Oligocene and lower Miocene, thereafter rapidly diversifying and multiplying. *Oliva* s.s. reached its greatest development during the late Miocene to middle Pliocene in the western Atlantic and is now represented by only four known species in this area. *Omogymna* reached its greatest development in the lower Miocene and decreased in diversity and numbers thereafter. The last known occurrence of this genus in the western Atlantic is the middle Pliocene Agueguexquite Formation of Mexico (see Akers, 1972, p. 30; 1974, p. 120).

Oliva s.s. is characterized by a medium-sized to large shell, ovate-cylindrical to cylindrical in outline, with a low to medium spire, and teleoconch whorls separated by a distinct channeled suture that usually has a border of callus. The last whorl generally conceals most of the preceeding whorls, terminating in a smooth outer lip. The parietal callus is usually thick, with many weak lirae, stronger anteriorly. The columella is strong and heavy, with two or more oblique plications around the base. The posterior canal is notch-like, with the aperture widening anteriorly, ending in an emarginated siphonal canal.

The subgenus *Omogymna* has a small to medium-sized shell similar to *Oliva* s.s. in most characteristics but with a narrow depressed posterior band on the whorls.

The genus *Jaspidella* is represented by small *Olivella*-like species, with a large, obtuse nucleus on a high spire. The parietal wall usually lacks any callus above the columella folds. *Jaspidella* may have evolved out of small *Agaronia*-like forms, making its first appearance in the Oligocene of Florida (Suwannee Limestone), as *"Olivella" liveoakensis* (Mansfield, 1937, p. 96). *Jaspidella* has a meager representation in the Tertiary of the western Atlantic, and is now represented by three known Recent species.

Today, olives are carnivorous gastropods that inhabit sandy bottoms in temperate to tropical seas. They generally prefer shallow to intertidal areas, but some species are known to occur rarely at much greater depths (Zeigler and Porreca, 1969, p. 69).

The members of the subfamily Olivinae often show considerable variation within a species. This is particularly true of some species from the Alum Bluff Group. Because of the large number of specimens available for this study, many variations have been shown to occur within a species, which might have resulted in overnaming with fewer specimens.

The author had found as constant criteria for differentiation of species within a genus or subgenus: the number and shape of the nuclear whorls and the nature of the first teleoconch whorl; the width and depth of the suture; the nature of the intrasutural callus; the overall nature of the slope of the spire (convex or concave). Other factors such as height of spire, number and strength of lirae and plications, degree of convexity or concavity of spire, extent of coverage of intrasutural callus, may be variable within a species.

III. ACKNOWLEDGMENTS

A very special note of gratitude goes to Drs. Harold E. and Emily H. Vokes, without whose constant encouragement and advice this paper would not have been possible. Gratitude is also expressed to them for the excellent photographs and the loan of many specimens from the Tulane University collections. A special thanks goes to Robert and the late Shirley Hoerle, West Palm Beach, Florida, and to Warren Blow, Washington, D.C., for the generous loan of specimens from their personal collections. The writer is also indebted to Thomas R.

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*The earliest known olivid is a species of *Strephonella, "Oliva" mississippiensis* Conrad, 1847, which was described from the Vicksburg Oligocene. Subsequent workers have generally placed this species in the genus *Agaronia*. Palmer (*in* Harris and Palmer, 1947, p. 410, pl. 63, figs. 17-19) reported similar forms from the Moody's Branch Marl, Jacksonian upper Eocene, near Montgomery, Louisiana.

Waller and Wendell P. Woodring, of the U.S. National Museum, and Druid Wilson, of the U.S. Geological Survey, for the loan of comparative material.

Finally, the writer is deeply appreciative of the help and constructive criticisms of the editorial committee, who have added much to this paper.

IV. SYSTEMATIC DESCRIPTIONS

Phylum MOLLUSCA
Class GASTROPODA
Subclass PROSOBRANCHIA
Order NEOGASTROPODA
Superfamily VOLUTACEA
Family OLIVIDAE Swainson, 1840
Subfamily OLIVINAE Swainson, 1840
Genus OLIVA Bruguière, 1789
Subgenus OLIVA s.s.

Oliva BRUGUIÈRE, 1789, Encycl. Méth. (Vers), v. 1, p. XV (genus without named species).

Type species: *Voluta oliva* Linnaeus (=*O. ispidula* of authors, not of Linnaeus) by tautonomy and monotypy.

Discussion: In the past, there has been much confusion about the correct citation for the author of the genus *Oliva*. There also has been confusion over the type species for the genus *Oliva*, as well as the correct subgenus for the modern species of *Oliva* of the western Atlantic and many of the related fossil forms.

Olsson and Harbison (1953, p. 182) summarized the situation well in their discussion of the *Oliva* from the Florida Pliocene:

"Authorship of the genus *Oliva* has been credited Martyn, 1786, Bruguière, 1789, and to Lamarck, 1799. Dall accepted Martyn as author of the genus and selected *Oliva corticaria* Martyn (*O. incrassata* Solander (*angulata* Lamarck)) in 1905 as type. This view was also shared by Woodring, 1928 and by Wenz, 1943. Martyn's generic names are now generally rejected since the author was not Linnean, but as he expressively stated, used his own system. No species was mentioned by Bruguière, 1789 in his description of the genus but it may be assumed that the name was derived from Linné's *Voluta oliva*. Lamarck, 1799, in the Prodrome mentioned but one species, the *Voluta oliva* Linné, under his description of *Oliva*. Thus *Oliva oliva* Linné is the type of the genus through tautonomy."

Olsson and Harbison recognized that *Oliva oliva* was a composite species, including *O. maura* Lamarck in part. *Oliva maura* has a depressed spire and a raised and thickened lip at the suture. For this reason, some authors (Olsson and Harbison, 1953, p. 182; Weisbord, 1962, p. 362) have placed the western Atlantic olives in the subgenus *Ispidula* Gray, 1847, with *O. ispidula* (of authors *non* Linneaus 1758) as the type of the subgenus. Wenz (1943, p. 1280) put *Ispidula* Gray, 1847, in synomony with *Oliva* Martyn, 1786.

Olsson and Dance (1966, p. 215-222) examined the types of the three Linnean olives: *Voluta porphyria, Voluta oliva* and *Voluta ispidula*. Their findings are summarized below. The reader is referred to the article for a more complete discussion, especially in reference to the differentiation of the true Linnean types.

Voluta oliva was found to be the type for the genus *Oliva* Bruguière, by tautonomy and subsequent monotypy. The tray in the Linnean collection with the name *Voluta oliva* contained five specimens. Four unmarked specimens in the tray were referable to *O. maura* Lamarck and are assumed to have been added to the collection after the death of Linneaus, but before it was acquired by the Linnean Society. The one numbered specimen was identified, upon comparison with *Oliva* specimens in the U.S. National Museum, as *Oliva ispidula* of many authors (*non* Linneaus, 1758). *Voluta ispidula* Linneaus, 1758 was found to be identical with *Oliva plicaris* Lamarck, 1811, which is a fossil species of *Agaronia* from the Burdigalian Miocene of France. Thus, *Ispidula* Gray, 1847, becomes a synonym of *Agaronia* Gray, 1839. *Oliva maura* Lamarck was thought to be a synonym of *O. oliva*, but since *O. oliva* is now recognized not to be synonymous with *O. ispidula, O. maura* Lamarck, 1811, becomes a valid species (= *O. vidau* Röding, 1798) of the subgenus *Carmione* (Zeigler and Porreca, 1969, p. 83).

OLIVA (OLIVA) WALTONIANA Gardner
Plate 1, figs. 1, 2

Oliva liodes subsp. *waltoniana* GARDNER, 1937, U.S. Geol. Surv. Prof. Paper 142-F, p. 379, pl. 46, figs. 2, 3.

Diagnosis: "Shell of only moderate altitude but rather stout and heavy. External surface smooth and very brightly polished. Spire only a little less than one-fifth the total altitude in the type but less than one-eighth in other individuals. Body whorl smoothly rounded both posteriorly and anteriorly, the maximum diameter falling a little behind the median line. Whorls probably 9 in all in the adult, 5 of these included in the conch and 4 in the

rather small, obtusely rounded protoconch. Initial turn minute, rather inflated but almost entirely submerged, the two succeeding volutions broadly rounded and increasing rather rapidly both in diameter and altitude; final whorl of the protoconch flattened laterally toward its close, increasing in altitude but scarcely at all in diameter. Boundary line between conch and protoconch very obscure, oblique, retractive, performing in the figured specimen about half a complete revolution, indicated by the more porcellaneous texture of the conch, the increased flattening of the whorl, and the deepening of the sutural channel. Conchal whorls of spire trapezoidal in outline, the degree of obliquity varying with the height of the spire. Incremental striae faint, least so toward the aperture. A polka-dotted color pattern discernible in some individuals. Sutural channel rather deep, undercutting the whorl behind it, partly concealed by the overhanging margin both of the whorl behind and the whorl in front of it. Aperture rather narrow, the margins approximately parallel throughout their posterior and medial extents. Labrum freebly constricted toward the suture but approximating the vertical, broadly and smoothly rounding into the siphonal notch in front. Parietal wall quite heavily corrugated except in the immediate environs of the posterior commissure, 8 rugae behind the heavy pillar callus, increasingly heavier, broader, and more cuneiform in outline anteriorly. Pillar reinforced near the base by 4 sharply overlapping folds of callus, terminating in heavy parietal rugae, the anterior the thinnest and the most clearly defined, obliquely directed toward the siphonal notch but evanescing before reaching it. A thinner wash spread across the base of the body, originating at a point about two-thirds of the distance from the posterior commissure to the anterior extremity and evanescing a short distance back from the outer margin of the siphonal notch, which it parallels through about half its extent. Siphonal notch only moderately deep and rather narrow, obliquely directed, its margins not quite parallel." (Gardner, 1937)

Dimensions of holotype: height 29.3 mm, diameter 13.4 mm.

Holotype: USNM 351282.

Type locality: USGS 3856, 6 miles west northwest of Mossyhead, Walton County, Florida (= TU 69).

Occurrence: Shoal River Formation, Florida; middle Miocene.

Figured specimen: Fig. 1, USNM 247885; height 25.5 mm, diameter 11.7 mm. Fig. 2, USNM 247886; height 4.7 mm, diameter 2.4 mm; locality of both TU 69a. Other occurrences: TU locality no. 69.

Discussion: Oliva waltoniana is a common member of the Shoal River fauna, representing the total olivid fauna from the Shoal River Formation, except for a single specimen of *O.* cf. *blowi*. Gardner (1937, p. 379) described *O. waltoniana* as a subspecies of *O. liodes*, not realizing that *O. liodes* belonged to the subgenus *Omogymna*. Because of this new assignment for *O. liodes*, as well as many other obvious differences, *O. waltoniana* is here raised to specific rank.

As with the other species of *Oliva* from the Alum Bluff Group, the four-whorled nucleus sets it apart from most of its relatives. Except for the subspecies *O. calhounensis*, *O. waltoniana* most clearly resembles *O. gatunensis* Brown and Pilsbry from the Gatun Formation of Panamá. *Oliva gatunensis* differs primarily in its three-whorled nucleus, slightly convex spire, shallow narrow suture and weaker lirae fading rapidly towards the posterior commissure.

OLIVA (OLIVA) WALTONIANA CALHOUNENSIS Drez, n. subsp.
Plate 1, figs. 3, 4

Diagnosis: Shell of medium size, relatively thin, body whorl smoothly rounded at both ends, slightly inflated, maximum diameter a little posterior to the mid-line. Eight to nine whorls in adult specimens, including a 4½-whorl naticoid nucleus; spire about one-fifth of the total height; straight to slightly convex in outline. First nuclear whorl minute, partially submerged, the following whorl increasing equally in width and height. The third and fourth whorls increasing rapidly in height, the last higher than the sum of the preceding whorls. The transition from nuclear to teleoconch whorls occurring over one-half of a volution, as a band of lighter-colored teleoconch material rises and overtakes the nuclear whorl, with a lateral flattening and deepening of the suture. A ribbon of callus on early post-nuclear whorls reaching up to the posterior edge of the preceding volution, gradually thickening and descending on later whorls until it occupies one-half to one-third of the lower visible portion of the penultimate whorl. Suture deeply channeled, narrow, with an overhanging ribbon of callus. Aperture narrow at the posterior end, widening upwards toward the anterior, and slightly flaring. Outer lip smooth, gently retracting toward the posterior commissure. A darker-colored band bordering the outside of the convex lip, widening anteriorly and continuing around to the siphonal canal notch. Parietal callus smooth and heavy at the posterior commissure, thinning in front of the commissure, thickening again anteriorly, with the callus intersecting the siphonal fasciolar band about halfway to the anterior end, the band widening as it cuts obliquely across the columella toward the siphonal notch, evanescing upon reaching it. Eight to ten single sharp lirae on

the parietal wall ending abruptly about one-fifth of the way to the posterior commissure, with two or three heavy lirae on the plications. Four to five plications on the base of the columella, stronger posteriorly, disappearing before reaching the siphonal notch. Siphonal notch moderately deep, wide, obliquely directed, with non-parallel margins.

Dimensions of holotype: height 31.1 mm, diameter 14.0 mm.

Holotype: USNM 247887.

Paratype: USNM 247888; height 9.0 mm, diameter 3.0 mm.

Type locality: USGS 10971, Turtle Lake Bluff, about 150 yards above the mouth of Fourmile Creek, Chipola River, Calhoun County, Florida [not located].

Occurrence: Chipola Formation, Florida; late lower Miocene. Oak Grove Sand, Florida; (?) late lower Miocene.

Figured specimens: Fig. 3, USNM 247887 (holotype). Fig. 4, USNM 247888 (paratype); locality same as holotype.

Discussion: The specimens of *O. calhounensis* were obtained from a lot in the U. S. National Museum collected by Mansfield in 1938, after the *Oliva* part of Gardner's U.S.G.S. Prof. Paper 142 had been published. Attempts by subsequent collectors to find the locality have proved unsuccessful.

There is one adult specimen with a crushed spire in Gardner's collection from the Oak Grove fauna (USGS 2646), which is referable to *O. calhounensis*. All the diagnostic characteristics are present, except for a defective nucleus.

Oliva calhounensis differs from *O waltoniana* s.s. by its consistently higher spire, less inflated outline near the posterior end, thinner shell, and more exserted nuclear whorls. Lirae and plications on the columella are generally more callused on *O. calhounensis*.

OLIVA (OLIVA?) BLOWI Drez, n. sp.
Plate 1, figs. 5, 6, 7

"*Oliva*, near *reticularis* Lamarck." DALL, 1903, Wagner Free Inst. Sci., Trans., v. 3, pt. 6, p. 1590.

Oliva cylindrica Sowerby. DALL, 1903, Wagner Free Inst. Sci., Trans., v. 3, pt. 6, p. 1590 (*not* of Sowerby).

Diagnosis: Shell of medium size, thick and heavy, subcylindrical in outline, with the periphery about one-third of the way from the posterior commissure. Nine to ten whorls in adult specimens, including a small papillary four-whorl nucleus; spire varying between one-eighth to one-fourth of the total height, slightly to strongly convex in outline. First nuclear whorl small, partially submerged, the following whorl increasing equally in width and height. The third whorl greatly expanded, increasing slightly more in height than width; the fourth whorl increasing in height but only slightly in width. The transition to teleoconch whorls obscure, characterized by a rapid vertical flattening of the fourth nuclear whorl and deepening of the suture. The first teleoconch whorl nearly vertical in outline, with a tendency to lateral flattening toward the end of the first volution. A ribbon of callus, straight to convex in outline, on the early post-nuclear whorls bordering the posterior edge of the preceding volution, the callus gradually thickening and descending on later whorls, occupying between one-third to nine-tenths of the penultimate whorl, depending upon the height of the spire. Suture deeply channeled, narrow, with an overhanging ribbon of callus. Aperture narrow at posterior commissure, gradually widening anteriorly. The outer lip nearly vertical, slightly retractive at the posterior commissure. A wide, depressed porcelaneous band present in juvenile specimens, occupying the posterior one-third of the body whorl, the band rapidly narrowing during the latter part of the third teleoconch whorl and completely disappearing in one-half of a volution. The extent of parietal callus varying considerably, usually heavy, with eight to 15 irregular lirae of shorter length posteriorly. The callus fading about three-fourths of the way to the posterior commissure, being barely discernible above the lirae. Four to five plications on the base of the columella, stronger posteriorly, evanescing before reaching the siphonal notch. The siphonal fasciolar band intersecting the parietal callus on the columella about half-way up the aperture, widening as it cuts obliquely across the columella toward the siphonal notch, fading around the notch. Siphonal notch moderately deep, sides slightly flaring.

Dimensions of holotype: height 34.8 mm, diameter 14.8 mm.

Holotype: USNM 247889.

Paratype A: USNM 247890; height 11.4 mm, diameter 5.4 mm.

Paratype B: USNM 247891; height 27.2 mm, diameter 11.9 mm.

Type locality: TU 459, east bank of Chipola River, steep bank about 1500 feet above the mouth of Taylor Lake Branch (NW ¼ Sec. 29, T1N, R9W), Calhoun County, Florida.

Occurrence: Chipola Formation, Florida; late lower Miocene. Oak Grove Sand, Florida; (?) late lower Miocene.

Figured specimens: Fig. 5, USNM 247889 (holotype). Fig. 6, USNM 247890 (paratype A); locality same as holotype. Fig. 7, USNM 247891 (paratype B); locality TU 555. Other occurrences: TU locality nos. 70, 457, 458, 546, 549, 554, 821, 825, 830, 951, 998, 1098.

Discussion: One juvenile specimen shows the wide posterior band over one complete whorl before fading away totally in less than one-half of a volution. The juvenile specimens seem to indicate an *Omogymna* assignment, but since this characteristic band is only present in extremely small individuals, not in adult forms, an assignment of *Oliva* s.s. seems best at this time.

Because of this unusual juvenile characteristic of *O. blowi,* a question arises as to the relationship between *Oliva* s.s. and *Omogymna*. This occurrence of a juvenile *Omogymna*-like band in *O. blowi* records an apparent evolutionary trend that led to the divergence of *Oliva* s.s. and *Omogymna*. Perhaps *Omogymna* is the ancestral form from which *Oliva* s.s. evolved, or possibly *Oliva* s.s. and *Omogymna* diverged from a common ancestor. Only careful examination of many fossil and Recent species of both subgenera, including the anatomical parts responsible for the posterior band, will reveal the evolutionary line.

Oliva blowi is the only Alum Bluff Group olivid that shows great variation. Along Ten Mile Creek and Farley Creek localities, as well as the lower beds on the Chipola River, the specimens show an average amount of variation but retain the moderately high spire, heavy parietal callus and the heavy stout lirae that gradually shorten and evanesce posteriorly. As one moves downstream on the Chipola River (higher stratigraphically), the spire has a tendency to decrease in height, the ribbon of callus occupying almost all of the penultimate whorl; thus the shell subsequently assumes a more cylindrical outline. The lirae also tend to become fewer in number and more evenly spaced, with a lighter covering of parietal callus.

Gardner mentions that she had specimens of *O. "liodes"* from four localities in the Oak Grove: USGS 2646, 5631, 2652, 7055. In the U.S.N.M. collections the author could only find specimens of olives from a single locality, USGS 2646 (Oak Grove, Yellow River, Okaloosa County, Florida). One lot contains two specimens referable to *O. blowi*. One is a small, high-spired individual; the second specimen is large, low-spired, subcylindrical, and similar to the figured specimen from TU 555 (fig. 7). The high-spired individual is probably Dall's *"Oliva,* near *reticularis* Lamarck," and the

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PLATE 1

Figures

1, 2. *Oliva (Oliva) waltoniana* Gardner 107
1. (× 2) USNM 247885; height 25.5 mm, diameter 11.7 mm.
Locality: TU 69a, Shoal River Formation.
2. (× 10) USNM 247886; height 4.7 mm, diameter 2.4 mm.
Locality: TU 69a, Shoal River Formation.
3, 4. *Oliva (Oliva) waltoniana calhounensis* Drez, n. subsp. 108
3. (× 2) USNM 247887 (holotype); height 31.1 mm, diameter 14.0 mm.
Locality: USGS 10971, Chipola Formation.
4. (× 10) USNM 247888 (paratype); height 9.0 mm, diameter 3.0 mm.
Locality: USGS 10971, Chipola Formation.
5-7. *Oliva (Oliva?) blowi* Drez, n. sp. 109
5. (× 2) USNM 247889 (holotype); height 34.8 mm, diameter 14.8 mm.
Locality: TU 459, Chipola Formation.
6. (× 10) USNM 247890 (paratype A); height 11.4 mm, diameter 5.4 mm.
Locality: TU 459, Chipola Formation.
7. (× 2) USNM 247891 (paratype B); height 27.2 mm, diameter 11.9 mm.
Locality: TU 555, Chipola Formation.
8. *Oliva (Oliva?)* cf. *O. blowi* Drez 112
(× 2) USNM 247892; height 29.4 mm, diameter 12.8 mm.
Locality: TU 69a, Shoal River Formation.
9, 10. *Oliva (Oliva?) vokesorum* Drez, n. sp. 112
9. (2) USNM 247893 (holotype); height 32.3 mm, diameter 12.4 mm.
Locality: TU 951, Chipola Formation.
10. (× 2) USNM 247894 (paratype); height 27.3 mm, diameter 10.8 mm.
Locality: TU 951, Chipola Formation.

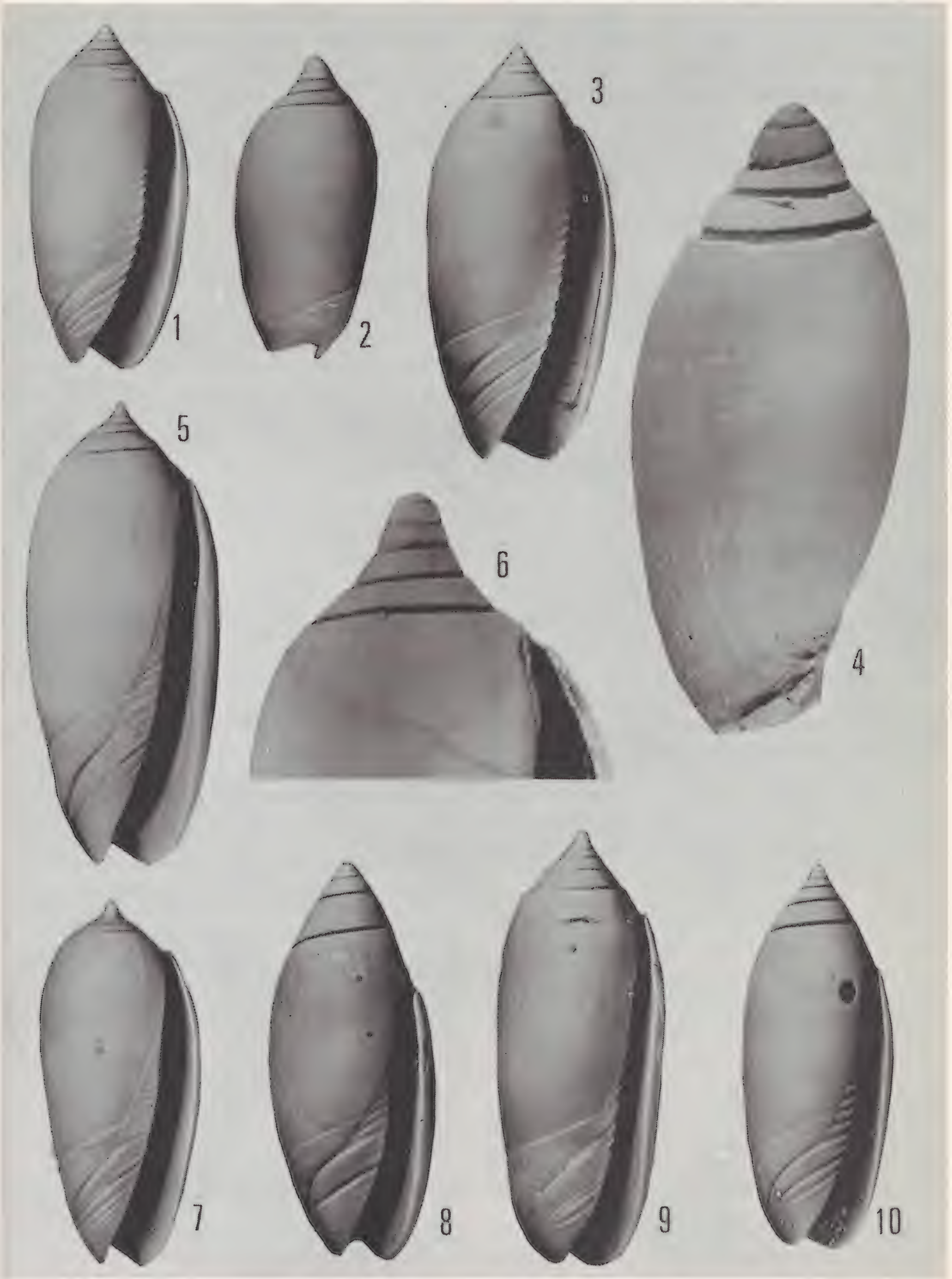

PLATE 1

low-spired specimen the one he cited as "*Oliva cylindrica* Sowerby" (1903, p. 1590).

Oliva blowi most closely resembles an undescribed species of *Oliva* that occurs in the "Silverdale beds" (early lower Miocene, North Carolina). This is the species that Kellum (1926, p. 41) and Richards (1943, p. 525) referred to *O. posti* Dall, originally described from the Tampa Limestone (early lower Miocene) of Florida (Dall, 1915, p. 49). This Silverdale species has the general characteristics of *O. blowi,* but the depressed posterior band does not disappear until the last adult whorl (fifth teleoconch). It also has a more slender outline, without the posterior bulge on the body whorl, a wider fasciolar band, and many fine lirae near the posterior commissure on the columella. The undescribed species also lacks the nearly vertical first post-nuclear whorl so characteristic of *O. blowi*. The presence of this undescribed Silverdale olivid species, which shows the same evanescing depressed posterior band as *O. blowi* on the adult body whorl, provides additional evolutionary evidence as mentioned earlier for the divergence of *Oliva* s.s. and *Omogymna*. *Oliva blowi* can be easily separated from its probable descendants, *O. reticularis* Lamarck, *O. reticularis trochala* Woodring, and *O. cylindrica* Sowerby, by its four-whorled nucleus and nearly vertical first teleoconch whorl.

This species is named for Warren C. Blow, U.S. National Museum, the one person most responsible for the writer's interest in paleontology.

OLIVA cf. O. BLOWI Drez
Plate 1, fig. 8

Diagnosis: A high-spired, thick and heavy, subcylindrical shell, with the maximum diameter approximating the median. The spire occupying about one-third of the total height, feebly convex in outline, convexity increasing on the body whorl. Nuclear whorls lost; 5½ teleoconch whorls in the adult. Early teleoconch whorls with a ribbon of callus approaching the posterior edge of the preceeding volution, gradually thickening and descending on later whorls, occupying two-thirds of the penultimate whorl just behind the outer lip. Suture deeply channelled, narrow, with a small overhanging ribbon of callus attached to the preceding whorl. Aperture moderately wide at the anterior end, rapidly narrowing toward the posterior commissure. Outer lip smooth, thick and vertical. Parietal callus generally heavy, but thinner near the posterior commissure, thickening rapidly anteriorly. Siphonal fasciole intersecting the callus about the median line of the columella, widening gradually as it cuts obliquely across the columella and fading around the siphonal notch. Eight single narrow lirae on the parietal callus, evanescing rapidly posteriorly. Two equally strong plications on the base of the columella, disappearing in the siphonal fasciole. Siphonal notch deep and narrow, margins parallel.

Occurrence: Shoal River Formation, Florida; middle Miocene.

Figured specimen: USNM 247892; height 29.4 mm, diameter 12.8 mm; locality TU 69a.

Discussion: It is unfortunate that the sole specimen of this interesting form available for study should have a defective nucleus. The extremely high spire, the strongly convex final whorl tapering at both extremities and the two strong plications make this a distinctive form. Although the figured specimens of *O. blowi* are generally low-spired, a few high-spired individuals of *O. blowi* from the Chipola Formation bear a close resemblance to the Shoal River specimen. The lack of a nucleus and part of the teleoconch whorls makes a definite assignment impossible at this time. This form seems to be the Shoal River equivalent of the Chipola species, *O. blowi,* if not identical to it.

OLIVA (OLIVA?) VOKESORUM Drez n. sp.
Plate 1, figs. 9, 10

Diagnosis: Shell of medium size, subcylindrical to cylindrical in outline, the maximum diameter falling about one-sixth of the distance from the posterior suture. Nine to ten whorls in adult specimens, including a four-whorl naticoid nucleus; a generally low conic spire varying between one-fourth to one-fifth of total height, straight to slightly concave in outline. Initial nuclear whorl minute, partially submerged, the following whorl increasing slightly in diameter but almost totally submerged in the third nuclear whorl. Third and fourth whorls continuing to increase slightly in width, but more rapidly in height, the transition to the teleoconch whorls occurring rather abruptly over one-fourth of a whorl, characterized by a rapid lateral flattening with a deepening and widening of the suture. Teleoconch whorls with a ribbon of callus, flat in outline and approaching the preceding suture, completely covering the intrasutural area of each spire shorl. Suture deep and wide, with a small overhanging ribbon of callus. Aperture generally narrow, widening gradually anteriorly. Outer lip vertical in outline, abruptly rounded at the posterior commissure. Parietal callus almost completely absent; six to nine strong single lirae on the columella, weaker posteriorly, ending one-

fifth of the way from the posterior commissure. Siphonal fasciole originating slightly less than half way from the posterior commissure, widening rapidly as it cuts obliquely across the columella and evanescing around the siphonal notch. One strong plication on the columella base, with three minor plications anteriorly, becoming weaker with maturity. Siphonal notch deep and narrow, with subparallel sides.

Dimensions of holotype: height 32.3 mm, diameter 12.4 mm.

Holotype: USNM 247893.

Paratype: USNM 247894; height 27.3 mm; diameter 10.8 mm.

Type locality: TU 951, Ten Mile Creek, about 1½ miles west of Chipola River (SE ¼ Sec. 12, T1N, R10W), Calhoun County, Florida.

Occurrence: Chipola Formation, Florida; late lower Miocene.

Figured specimen: Fig. 9, USNM 247893 (holotype). Fig. 10, USNM 247894 (paratype); locality same as holotype. Other occurrences: TU locality nos. 70, 457, 546, 655, 830.

Discussion: Oliva vokesorum is confined to Ten Mile Creek, except for one specimen from a Chipola River locality (TU 457), which is just above the lower contact of the Chipola Formation. In the Chipola fauna it is most easily confused with *O. liodes,* especially specimens of *O. liodes* that are waterworn, or that show only a microscopic posterior depressed band. In addition to the obvious feature of the depressed posterior band on the whorls of *O. liodes, O. vokesorum* differs in its more cylindrical shape, wider and deeper suture, general lack of parietal callus, one large plication (with three weaker plications anteriorly) on the columella, fewer and stronger lirae, trapezoidal-shaped callus between sutures, and narrow aperture.

Oliva vokesorum also resembles *O. sayana* Ravenel, which is the dominant olivid along the Atlantic and Gulf Coast today; the latter differs in having a three-whorled nucleus, generally larger size, wider aperture, heavy parietal callus, weaker lirae, wider and deeper suture and a slight bulging of the body whorl. Fossils olives from the Jackson Bluff Formation (Choctawhatchee Group, lower Pliocene) have been referred to *O. sayana* by Mansfield (1930, p. 51) and are probably the descendants of *O. vokesorum.*

One juvenile specimen (TU 951), which seems referable to this species, bears a small posterior band that disappears over the last quarter of the second teleoconch whorl. This is one whorl less than the three in which *O. blowi* loses its depressed posterior band. As with *O. blowi,* there remains some doubt about an *Oliva* s.s. assignment for this species. For a more complete discussion of the possible implications see *O. blowi* (above).

O. vokesorum is named for Drs. Harold E. and Emily H. Vokes, without whose help this paper would have never been written.

Subgenus OMOGYMNA Von Martens, 1897

Omogymna VON MARTENS, 1897, Conchologische Miscellen II, p. 157.

Type species: *Oliva paxillus* Reeve, by monotypy.

"Unterabtheilung der Gattung *Oliva,* dadurch charakterisirt, dass die äusserste (letzte) Schalenschicht den letzten Umgang nicht in seiner ganzen Ausdehnung einnimmt, sodern nach oben mit einer scharf gezogenen schiefen Linie endigt, welche von der Mündungswand ausgehend, nach aussen mehr und mehr gegen die Naht zu aufsteigt. Der oberste Theil der letzten Umgangs entbehrt demgemäss der letzten Auflagerung, die auf ihm befindlichen Flecke sind daher schärfer begrenzt und von etwas anderem dunklerem Farbenton, als auf den übrigen Theile der Schale. Die Nahtrinne ist sehr schmal, kaum sichtbar; der sichtbare Theil der vorhergehenden Windung ist wie bei den normalen Oliven in siener unteren Hälfte von einer wulstigen Auflagerung bedeckt.

Ob die Auflegerung, welche mit der shiefen Ebene endigt, vom Fuss oder vom Mantel gebildet wird, lässt sich nicht sagen, da die Weichtheile noch nicht bekannt sind. Mantel oder Fuss dürften aber voraussichtlich auch einen Unterschied von den normalen Oliven zeigen.

Die schiefe Linie macht gewissermassen den Eindruck, als ob ein Kleindungsstück von der Schulter herabgleite, daher die Benennung. Sie steht nicht bei allen Exemplaren dersleben Art in gleicher Höhe.

Bis jetzt habe ich diese eigenthümliche Bildung nur an einer Art gesenhem, nämlich der folgenden." (Von Martens, 1897).

Discussion: To the author's knowledge, the original description *Omogymna* (Von Martens, 1897, p. 157) has not been quoted in a work on western Atlantic olivids to date, and is reproduced here.

As with *Oliva* s.s., over the years there has been confusion about the authorship and type species of this interesting group. Dall (1903, p. 1574), in describing the Chipola fauna, made mention of the occurrence of this subgenus, as ". . . a species of the group *Oliva* called by von Martens *Omogymna,*" listing the species *Oliva (Omogymna) mar-*

tensii Dall in his checklist (p. 1576) as well as figuring it (pl. 58, fig. 4). Woodring (1928, p. 226) noted the occurrence of a species of *Omogymna* from the Cercado Formation of Santo Domingo, *Oliva (Omogymna) gradata* Gabb, attributing *Omogymna* to Dall (1903) with the type by monotypy, *Oliva (Omogymna) martensii* Dall. Tomlin (1934) rectified the position of *Omogymna*, reïnstating Von Martens as the author and *Oliva (Omogymna) paxillus* Reeve as the type species.

Omogymna is characterized by a depressed posterior band on the body whorl, which may or may not be visible on the spire whorls, depending upon the amount of intrasutural callus. The width of the band may vary considerably from species to species, usually attaining a constant width by maturity. On juvenile specimens the posterior band can occupy up to two-thirds of the body whorl, gradually narrowing and becoming more depressed with maturity.

OLIVA (OMOGYMNA) LIODES Dall

Plate 2, figs. 1, 2

Oliva liodes DALL, 1903, Wagner Free Inst. Sci., Trans., v. 3, pt. 6, p. 1576 (name only), pl. 58, fig. 1.

Oliva liodes Dall. MAURY, 1922, Bulls. Amer. Paleontology, v. 9, no. 38, p. 45.

Oliva liodes Dall. GARDNER, 1937, U. S. Geol. Surv. Prof. Paper 142-F, p. 378, pl. 46, fig. 1.

Oliva cf. *liodes* Dall. GARDNER, 1945, Geol. Soc. Amer., Memori 11, p. 216.

Not *Oliva liodes* Dall. MASSON and ALENCASTER-IBARRA, 1951, Asoc. Mex. Geol. Petrol., Bol., v. 3, p. 210, fig. 23.

Not *Oliva (Oliva) liodes* Dall. PERRILLIAT-MONTOYA, 1963, Paleontologia Mexicana, no. 14, p. 23, pl. 5, figs. 4, 5. (A new, unnamed species.)

Not *Oliva (Oliva) liodes* Dall. WOODRING, 1964, U. S. Geol. Surv. Prof. Paper 306-B, p. 276. (Fragments of two unknown species.)

Diagnosis: "Shell of moderate dimensions for the group but thick and heavy, smooth, and polished and subcylindrical in outline, the maximum diameter falling a little behind the median line. Spire very low, approximately one-sixth the total altitude of the shell, tapering rather unevenly in the apical region owing to the more rapid enlargment of the later volutions. Whorls 8 in all in the type, 9 in larger individuals, 4 or 5 of them included in the conch and 4 in the small, smooth knob of a protoconch. Initial turn minute and almost entirely submerged; succeeding turns broadly rounded, all but the second increasing more rapidly in altitude than in diameter, the final whorl of the protoconch flattening laterally toward its close. Bounding line between conch and protoconch obscure, indicated by the more porcellaneous texture of the conch, the greater lateral flattening, and the more deeply impressed suture. Whorls of spire trapezoidal in outline, the earlier whorls increasing more slowly in diameter than the later. Incremental striae feeble, least so toward the aperture. Sutural channel profound, deeply undercutting the preceding turn, partly concealed by the acute overhanging margins. Aperture narrow, the sides rudely parallel through their posterior and medial extent. Outer lip smooth, sharp-edged, almost vertical, very feebly contracted near the suture, rounding smoothly anteriorly into the siphonal notch. Parietal wall scored with numerous transverse corrugations, which become increasingly lower and less produced and commonly evanesce altogether toward the posterior commissure. Base of pillar heavily reinforced with 4 or 5 overlapping folds of callus which die out near the siphonal notch; posterior margin of basal callus intersecting the labium about one-third of the way from the anterior to the posterior extremity of the shell, cutting obliquely across the base of the shell toward the anterior notch, where it almost but not quite evanesces, faintly discernible upon the labrum at a distance of about 3 millimeters from the outer margin. Siphonal notch broad and deep. The margins parallel and obliquely directed." (Gardner, 1937)

Dimensions of holotype: height 27.0 mm, diameter 11.5 mm.

Holotype: USNM 113971.

Type locality: USGS 2212, Ten Mile Creek near Chipola River, Calhoun County, Florida (= TU 546).

Occurrence: Chipola Formation, Florida; late lower Miocene. Oak Grove Sand, Florida; (?) late lower Miocene. (?) Guajalote Formation, Tamaulipas, Mexico; late lower Miocene.

Figured specimens: Fig. 1, USNM 247895; height 30.5 mm, diameter 13.6 mm; TU locality 546. Fig. 2, USNM 247896; height 9.5 mm, diameter 3.9 mm; TU locality 459. Other occurrences: TU locality nos. 70, 91, 196, 456, 457, 458, 547, 548, 549, 550, 554, 555, 655, 708, 709, 711, 768, 810, 817, 820b, 821, 824, 825, 830, 831, 949, 950, 951, 998, 999, 1019, 1021, 1050, 1052, 1097, 1098. (?) USGS 13455, 14584, 13588. Bascom No. 2 well, Mobile, Alabama (1241 feet, Chipola horizon).

Discussion: In this species the spire varies between one-half and one-ninth of the total height and is straight to strongly concave in outline. There are nine to ten whorls in adult specimens, the posterior edge of the body whorl on some low-spired individuals rising during the last half of the body whorl but not reaching the top of the penultimate whorl. The transition between the nuclear and teleoconch whorls is gradual over the last half turn of the fourth nuclear whorl, as

a whitish band of teleoconch material rises and overtakes the nuclear material.

On juvenile specimens a wide band occupies the posterior third of the whorl, slowly narrowing to a band of constant width (1.2 mm or less) after two and one-half to three teleoconch whorls. The band has a rough undulating edge, which is sharp to the touch. This band is exposed on the spire whorls, with a ribbon of callus reaching up to but not covering the depressed band.

Dall (1903, pl. 58, fig. 1) originally figured *O. liodes*, but he did not describe it. Gardner (1937, p. 378) described the species and placed it in *Oliva* s.s., failing to notice the thin depressed posterior band. This band is extremely thin on the type and on Gardner's material (0.2-0.5 mm), which might explain the oversight*. Over 2500 specimens of *O. liodes* were available to the author for examination, as compared to the 38 that Gardner had. Many of the specimens have the posterior band developed enough for observation with the unaided eye, but most specimens require slight magnification for positive identification (see pl. 2, fig. 1b). A quick field method is to feel the posterior edge of the body whorl for a sharp undulating edge, which is the knife-like edge of the posterior band.

Oliva liodes was described by Gardner (1937) as belonging to the *O. sayana* group. Although *O. liodes* does resemble *O. sayana* superficially, the presence of the depressed posterior band, the smaller size, three-whorled nucleus, wider and deeper suture and a narrower aperture separate the two species.

Maury (1922, p. 45) reported *O. liodes* at the 1241-foot level of the Bascom No. 2 well, in Mobile, Alabama, which she referred to the Chipola horizon. The author attempted to examine the specimen(s), but they apparently have been temporarily misplaced at the Paleontological Research Institution.

Gardner (1945, p. 216) noted the occurrence of some imperfectly preserved molds of an olivid from the Guajalote Formation (USGS 13455, 13584, 13588) of Mexico, which she tentatively referred to *O. liodes*. If these molds are truly *O. liodes*, then this would greatly extend the geographic range of the species although not the stratigraphic range, as the formation is correlated with the Chipola.

Perrilliat Montoya (1963, p. 23) figured a species from the Agueguexquite Formation of Mexico, which she referred to *O. liodes*. A comparison of Agueguexquite specimens with those of *O. liodes* from the Chipola shows that those from the Agueguexquite are markedly different. The Mexican specimens have a three-whorled, exserted nucleus, a shallow narrow suture, a convex ribbon of callus on the spire whorls, a larger height/diameter ratio, a narrower aperture, heavier unpaired lirae, a prominent rounded shoulder and lack the depressed posterior band. The specimens referred by Perrilliat Montoya to *O. liodes*, from the Agueguexquite Formation (her locality = TU 1046), belong to an unnamed species of *Oliva* s.s.

Masson and Alencaster-Ibarra (1951, p. 210, fig. 23) figured a species as *O. liodes* from the Filisolo Formation (= TU 1095) of Mexico. The figure in the publication is extremely poor, but the description seems adequate for a comparison. The height/diameter ratio is much smaller (3.75) than for any specimen of *O. liodes* that the author has seen from the Chipola Formation. The specimens have three plications, as opposed to four or five for Chipola specimens. Also, the protoconch-teleoconch transition in *O. liodes* is gradual over one-half of a turn, but the Filisolo specimens have an abrupt and profound change. Masson and Alencaster-Ibarra's material appears not to be related to *O. liodes*.

Oliva liodes is the most common and widespread of the olivids in the Alum Bluff Group, occurring in both the Chipola and Oak Grove faunas. It is present at almost all localities. Although not as numerous as in the Chipola Formation, it is well represented in the Oak Grove Sand. One lot from Gardner's collection (USGS 2646) identified as *O. liodes*, also contained specimens of *O. martensii*, *O. calhounensis*, and *O. blowi*, in addition to *O. liodes*. The Oak Grove specimens are typical of the species.

The shell of *O. liodes* is large for the subgenus *Omogymna*, only *O. (Omogymna)*

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*Olsson maintains that the criteria selected by the author for the placement of *O. liodes* in the subgenus *Omogymna* are not valid, but Von Martens (1897) did not specify any minimum width for the depressed posterior band. Since the nature of the band on juvenile specimens of *O. liodes* and *O. martensii* are similar and only differ in size on mature specimens, the author feels justified in his assignment.

valens Jung, 1971, from the Miocene of Carriacou, West Indies, being of comparable size. *Oliva valens* differs from *O. liodes* in having a three-whorled nucleus, fewer teleoconch whorls, only three plications on the base of the columella, and a wider posterior band on adult specimens.

Oliva liodes shows faint traces of a color pattern on certain individuals, either under visible or ultraviolet light. The pattern is not bold enough to be photographed, but appears to be similar to the general pattern of *O. sayana* (Recent, Atlantic and Gulf Coasts of United States).

In the Chipola fauna, *O. liodes* could be confused with *O. vokesorum;* the latter can best be separated by the lack of the depressed posterior band, as well as the many other crieria already mentioned.

OLIVA (OMOGYMNA) MARTENSII Dall
Plate 1, figs. 3-5

Oliva (Omogymna) martensii DALL, 1903, Wagner Free Inst. Sci., Trans., v. 3, pt. 6, p. 1576 (name only), pl. 58, fig. 4.

Oliva (Omogymna) martensii Dall, GARDNER, 1937, U. S. Geol. Surv. Prof. Paper 142-F, p. 380.

Diagnosis: "Shell small for the group but moderately thick and heavy, subcylindrical in outline, smooth and highly polished. Spire approximately one-fourth as high as the entire shell, smoothly tapering, commonly a little convex, the protoconch appearing as a minute apical knob. Whorls 8 in all, probably only 3 of them included in the protoconch. Initial turn of protoconch minute, largely submerged; succeeding volution broadly rounded, increasing slowly in altitude but rather rapidly in diameter, the 2 remaining volutions increasing in altitude but scarcely at all in diameter. Boundary line between conch and protoconch obscure, indicated by the more porcellaneous texture of the conch, the increased flattening of the whorl, and its more rapid enlargement, and the deepening of the suture. Whorls of spire trapezoidal in outline, the body rounding smoothly toward the suture, a band a trifle narrower than the penult planed off from the body directly in front of the suture, margined anteriorly by a sharp clean-cut edge. Sutural channel undercutting the whorl behind it, deep but not very wide, overhung by the free and proximate margins of both the preceding and the succeeding volutions. Aperture rather narrow, the margins subparallel through their posterior and medial extent. Outer lip thin, sharp, approximately vertical. Parietal callus smooth and moderately heavy at the posterior commissure, thinning out just in front of the commissure, then thickening again and becoming increasingly heavy and heavily corrugated anteriorly, spreading out rather abruptly at about two-thirds of the distance from the commissure to the anterior extremity in two major, overlapping folds with minor surficial sulci; major folds swinging from the base of the pillar across toward the siphonal notch but evanescing before reaching it. A lighter but more widely spread coat of glaze extending from about half way down the apertural wall obliquely across the base of the body until it parallels the outer margin of the notch, where it gradually evanesces without mounting the labrum. Siphonal notch rather narrow but very deep, the margins parallel and obliquely directed." (Gardner, 1937).

Dimensions of holotype: height 19.5 mm, diameter 8.5 mm.

Holotype: USNM 113974.

Type locality: USGS 2212, Ten Mile Creek, near Chipola River, Calhoun County, Florida (= TU 546).

Occurrence: Chipola Formation, Florida; late lower Miocene. Oak Grove Sand, Florida; (?) late lower Miocene.

Figured specimens: Fig. 3, USNM 247897; height 21.7 mm, diameter 8.7 mm; TU locality 830. Fig. 4, USNM 247898; height 18.7 mm, diameter 8.5 mm; TU locality 546. Fig. 5, USNM 247899; height 6.1 mm, diameter 2.9 mm; TU locality 830. Other occurrences: TU locality nos. 70, 91, 456, 457, 458, 459, 547, 548, 549, 554, 555, 655, 708, 787, 810, 817, 818, 820b, 821, 824, 825, 827, 831, 951, 998, 999, 1050, 1051, 1097, 1098.

PLATE 2

Figures Page

1, 2. *Oliva (Omogymna) liodes* Dall 114
1. USNM 247895; height 30.5 mm, diameter 13.6 mm.
Locality: TU 546, Chipola Formation.
(Fig. 1a × 2; fig 1b × 10).
2. (×10) USNM 247896; height 9.5 mm, diameter 3.9 mm.
Locality: TU 459, Chipola Formation.
3-5. *Oliva (Omogymna) martensii* Dall 116
3. USNM 247897; height 21.7 mm, diameter 8.7 mm.
Locality: TU 830, Chipola Formation.

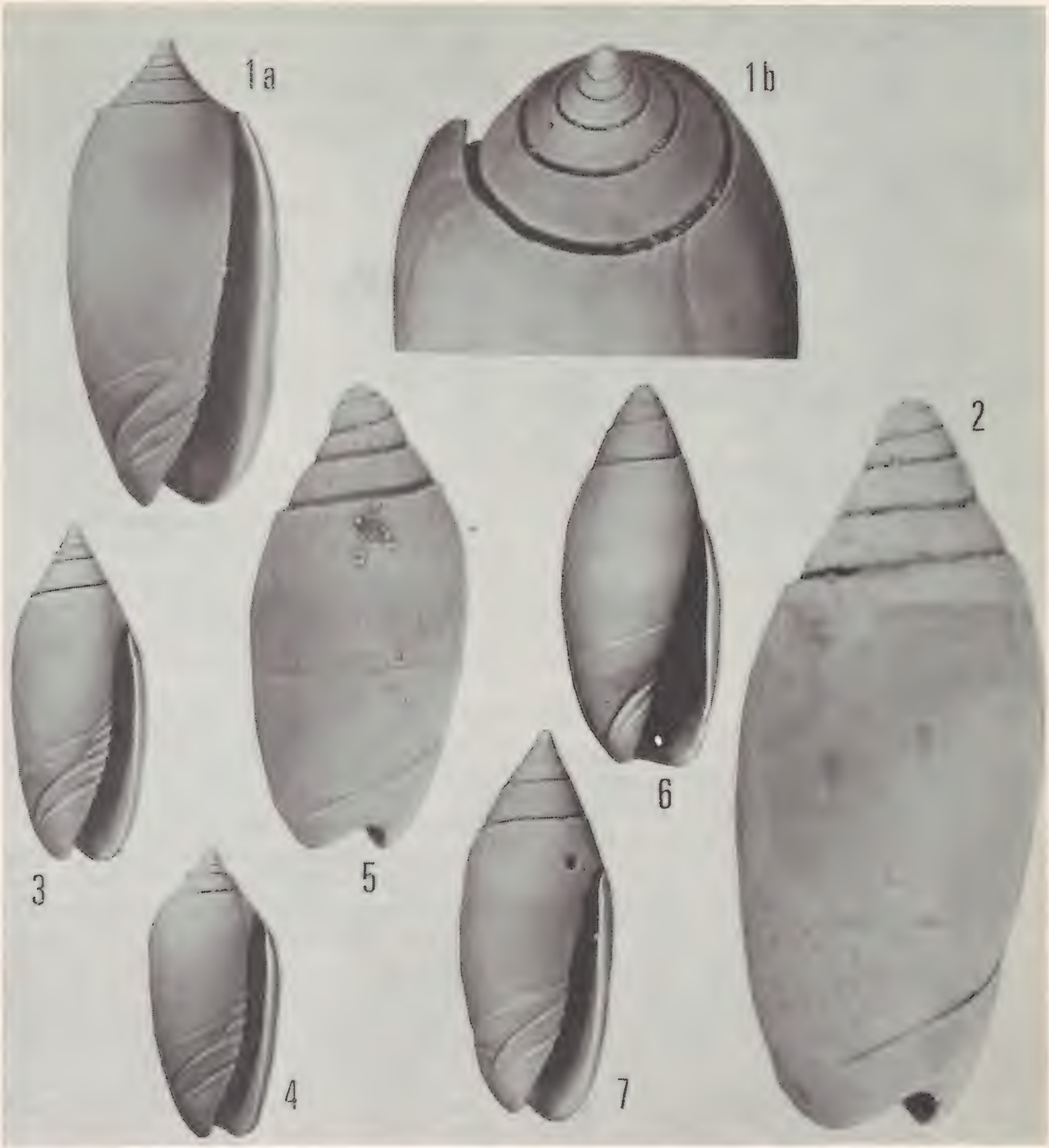

PLATE 2

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4. (× 2) USNM 247898; height 18.7 mm, diameter 8.5 mm.
   Locality: TU 546, Chipola Formation.
5. (× 10) USNM 247899; height 6.1 mm, diameter 2.9 mm.
   Locality: TU 830, Chipola Formation.
6. *Oliva (Omogymna) gardnerae* (Richards) 119
   (× 2) USNM 247900; height 24.4 mm, diameter 9.5 mm.
   Locality: TU 562, Silverdale Beds, North Carolina.
7. *Jaspidella cofacorys* (Gardner) 119
   (× 4) USNM 247901; height 12.2 mm, diameter 5.1 mm.
   Locality: TU 554, Chipola Formation.

Discussion: As with *O. liodes, O. martensii* was only figured by Dall (1903, pl. 58, fig. 4) and not described until Gardner (1937, p. 380) did her systematic work on the Alum Bluff Group.

The four-whorled nucleus sits on top of a low convex spire like a little knob. The posterior band is smooth in outline but not sharp to the touch as with *O. liodes,* due to the smooth edge along the top of the band. On juvenile specimens the wide, glossy, posterior band occupies about two-thirds of the body whorl, gradually decreasing in width on subsequent volutions and reaching a constant width (1.2 to 2.4 mm) after two and one-half to three teleoconch whorls. The only change during maturation is a general subsiding of the band. The band on juvenile specimens gives a *Strephonella*-like appearance to the juvenile shells. But the band is glossy and depressed on the juvenile specimens of *O. martensii;* in *Strephonella* the posterior section is not depressed and the dividing line is an impressed groove.

Oliva martensii is of average size for species of the subgenus *Omogymna.* Its distribution in the Chipola is second only to *O. liodes* in number of specimens. It is generally uncommon on the upper part of Ten Mile Creek, increasing in abundance downstream. On Farley Creek, it becomes the dominant member of the olivid fauna and attains a generally larger size. This species is also represented in collections from the Oak Grove fauna by three juveniles (USGS 2646) and one adult specimen (TU 91). These specimens appear to be identical with the Chipola material, except that the posterior band is slightly narrower than on typical Chipola specimens.

Some confusion may arise in separating the juvenile forms of *O. blowi, O. liodes* and *O. martensii,* since all possess a wide posterior band. When comparing juvenile specimens with the same number of teleoconch whorls, the separation becomes simple. *Oliva liodes* and *O. martensii* are both relatively cylindrical in outline, whereas *O. blowi* has a distinct bulge at the posterior of the body whorl and has a strongly convex spire. *Oliva blowi* can be further distinguished from the other two by its knob-like nucleus and the rapid rate of narrowing and eventual disappearance of the posterior band during the third teleoconch whorl. *Oliva martensii* is always considerably smaller and narrower than *O. liodes* or *O. blowi* with the same number of teleoconch whorls. The posterior band is never as wide on the earliest juvenile specimens of *O. liodes* as it is on the third teleoconch whorl of *O. martensii.* The smaller size of *O. martensii,* the consistently wider posterior band, and the two strong plications on the columella are sufficient characteristics to distinguish it from *O. liodes.*

The width of the posterior band is essentially constant on *O. liodes* and *O. martensii* after completion of the third teleoconch whorl. Therefore, as *O. liodes* and *O. martensii* reach maturity, the posterior band occupies a smaller percentage of the body whorl. This is not true in all species of *Omogymna,* including the type of the subgenus, *Oliva (Omogymna) paxillus* Reeve, Recent of the Indo-Pacific. Specimens at hand show that even on adult examples the band has not achieved a constant width for the body whorl. Apparently the species of *Omogymna* with a constant-width posterior band are limited to the western Atlantic Tertiary. Possibly, these forms should be assigned to a different group from the typical *Omogymna* species of the Recent. A thorough study of the worldwide *Omogymna* fauna is needed in order to answer this question.

Some specimens exhibit a faint color pattern under visible and/or ultraviolet light, but the patterns are not sufficiently intense to be photographed. *Oliva martensii* had a rather complex color pattern, consisting of a series of small dots just anterior to the revolving posterior band, with a narrow dashed band around the middle of each whorl. The overall background pattern resembles a miniature *O. sayana* (Recent, western Atlantic), but the revolving line around the middle of the whorls and the series of dots resembles the modern *O. paxillus* from the Indo-Pacific.

As with *O. blowi, O. martensii* seems also to have had its ancestry in the "Silverdale" fauna (lower Miocene). Richards (1943, p. 525) described the species *"Olivella" gardnerae* from the marl ("Silverdale beds") of

the Trent Formation at Silverdale, North Carolina.* From his description, he apparently described a juvenile form of the *Omogymna* ancestor of *O. martensii*. An adult figure (see Pl. 2, fig. 6) of *Oliva (Omogymna) gardnerae* is furnished for comparison. It differs mainly from *O. martensii* in the fact that the posterior band does not attain a constant width until the final adult whorl. This species also has a more exserted nucleus, with the intraspinal callus not covering all of the preceding whorl in the early teleoconch whorls. The posterior band on the Silverdale species is not as depressed as on *O. martensii*, and the spire tends to have a high trapezoidal outline, rather than the lower convexity of the younger species.

The *O. martensii* line seems to continue in the form of *O. gradata* from the Miocene Cercado Formation of the Dominican Republic. *Oliva gradata* is close to *O. martensii*, but the exserted two and one-half-whorled nucleus serves best to differentiate the two species. On the specimens of *O. gradata* available to the author from the Cercado Formation (TU 1230), the posterior band is consistently wider (2.4 - 2.5 mm) than that of *O. martensii*, as well as more depressed. Due to the lack of any juvenile specimens of *O. gradata* no comparison can be made of the different rates of band narrowing on the early whorls of the two species.

Genus JASPIDELLA Olsson, 1956

Jaspidella OLSSON, 1956, Acad. Nat. Sci. Phil., Proc., v. 108, p. 212.

Type species: *Voluta jaspidea* Gmelin, by original designation.

"Oliviform shell with a high spire of several whorls terminating in an obtuse nucleus. Sutures narrowly grooved, the collar of the preceding whorl appressed. No callous wash on the parietal wall. Pillar structure is a low, finely plaited fold at the end of the columella. Fasciole wide and undivided. Internally with a fold at the end of the pillar, the internal walls of the spire whorls reabsorbed. Operculum present, chitinous. The radular ribbon is very long, with numerous teeth (±100), the rachidian tooth tricuspidate." (Olsson, 1956)

Discussion: This genus of Olivinae was first recognized by Olsson (1956, p. 212) during his studies of the Olivellinae. Examining the radula he noticed that those of *"Olivella" jaspidea* were like the Olivinae and not the Olivellinae. The genus *Jaspidella* is still included in the Olivellinae by many workers due to its small size, but as with the genus, *Strephonella*, it belongs in the Olivinae, based on the radula.

As noted in the description above, the genus in the fossil state can be best characterized by the general lack of parietal wall callus and a low, finely plaited fold at the anterior end of the columella. *Jaspidella* has a meager representation in the western Atlantic Tertiary. The oldest known form is *J. liveoakensis* (Mansfield, 1937), from the Oligocene of Florida. *Jaspidella* is represented in the Recent western Atlantic by three known species.

JASPIDELLA COFACORYS (Gardner)
Plate 2, fig. 7

Olivella cofacorys GARDNER, 1937, U. S. Geol. Surv. Prof. Paper 142-F, p. 383, pl. 46, figs. 10, 11.

Jaspidella cofacorys Gardner, OLSSON, 1956, Acad. Nat. Sci. Phil., Proc., v. 108, p. 212.

Diagnosis: "Shell of moderate dimensions for the group, rudely elliptical in outline, smooth and very highly polished. Spire rather elevated, the whorls closely overlapping one another like a bandage. Body broadly and smoothly rounded. Whorls 5½ in all, 4 of this number included in the conch. Initial whorl broad and full, immersed at the tip; succeeding half-turn high, feebly convex. Dividing line between conch and protoconch indicated by a slight difference in the texture of the shell and by the abrupt initiation of the sutural channel. Postnuclear whorls of the spire trapezoidal in outline, increasing regularly and not very rapidly in diameter. Sutural channels very narrow, not undercutting the preceding volution, margined in front by the sharp edge of the succeeding turn. Incremental striae exceedingly feeble. Aperture narrow, cuneiform in outline, acutely angulated posteriorly. Outer lip thin, sharp, approximately vertical, slightly patulous anteriorly; posterior two-thirds of ultima free from callus, even at the posterior commissure. Basal coat of glaze cutting obliquely across from a point a little less than halfway from the posterior to the anterior extremity of the aperture, the labral margin parallel throughout its later extent with the outer arm of the siphonal notch. Body wall obscurely corrugated with 6 or 8 transverse sulci. Base of pillar reinforced with a narrow but

*See E. H. Vokes, 1967, p. 140, for discussion of the relationship of the "Silverdale Beds" and the Trent Formation.

heavy deposit of callus laid parallel to the obtuse pillar margin, bearing a few secondary sulci directed toward the siphonal notch but evanescing before reaching it. Anterior emargination very broad but shallow, approximately horizontal." (Gardner, 1937)

Dimensions of holotype: height 11.6 mm, diameter 4.7 mm.

Holotype: USNM 328665.

Type locality: USGS 2213, one mile below Bailey's Ferry, Chipola River, Calhoun County Florida (= TU 457).

Occurrence: Chipola Formation, Florida; late lower Miocene.

Figured specimen: Fig. 7, USNM 247901; height 12.2 mm, diameter 5.1 mm; TU locality 554. Other occurrences: TU locality nos. 457, 458, 547, 548, 810, 950, 1020.

Discussion: Jaspidella cofacorys is confined in its distribution to the Chipola River, being absent along Ten Mile and Farley Creeks. It is most common in the lower beds along the river, represented by only two specimens from the upper part of the section on the Chipola River (TU 547).

Jaspidella santidominici (Maury), from the Gurabo Formation of the Dominican Republic is extremely close in general outline and appearance to *J. cofacorys* and probably represents a descendant of the Chipola species. *Jaspidella santidominici* differs from *J. cofacorys* in having a much larger bulbous nucleus and narrower sutures. The appressed posterior part of the body whorl and the more inflated anterior, gives a distinct flaring to the aperture of *J. santidominici*.

V. LOCALITY DATA

The following are Tulane University fossil localities. All localities are in the Chipola Formation, Calhoun County, Florida, except where noted:

69. Shoal River Fm., type locality, Shell Bluff, Shoal River (NW ¼ Sec. 4, T3N, R21W), about 3½ miles north of Mossyhead, Walton Co., Florida.

69a. Shoal River Fm., first ravine upstream from Shell Bluff, Shoal River (NW ¼ Sec. 4, T3N, R21W), about 3½ miles north of Mossyhead, Walton Co., Florida.

70. Ten Mile Creek, at bridge of Florida Highway 73 (NW ¼ Sec. 12, T1N, R10W).

91. Oak Grove Sand (type locality), west bank of Yellow River, about 100 yards below bridge at Oak Grove (NE ¼ Sec. 20, T5N, R23W), Okaloosa Co., Florida.

196. Ten Mile Creek, about ¼ mile upstream from bridge of Florida Highway 73 (NE ¼ Sec. 11, T1N, R10W).

456. Ten Mile Creek, about ¼ mile downstream from bridge of Florida Highway 73 (NE ¼ Sec. 12, T1N, R10W).

457. West bank of Chipola River, about ½ mile below Ten Mile Creek (SW ¼ Sec. 17, T1N, R9W).

458. East bank of Chipola River above Farley Creek (SW ¼ Sec. 20, T1N, R9W).

459. East bank of Chipola River, steep bank about 1500 feet above the mouth of Taylor Lake Branch (NW ¼ Sec. 29, T1N, R9W).

546. Ten Mile Creek, about 1½ miles west of Chipola River (NW ¼ Sec. 12, T1N, R10W).

547. West bank of Chipola River, about 2000 feet above Four Mile Creek (SW ¼ Sec. 29, T1N, R9W).

548. West bank of Chipola River at bend about 1800 feet south of mouth of Farley Creek (NW ¼ Sec. 29, T1N, R9W).

549. East bank of Chipola River, about ¼ miles below Four Mile Creek (NE ¼ Sec. 32, T1N, R9W).

550. Chipola River, east bank 1¼ miles below Ten Mile Creek (NE ¼ Sec. 20, T1N, R9W).

554. East bank of Chipola River at power line crossing (SW ¼ Sec. 17, T1N, R9W).

555. East bank of Chipola River, about 1000 feet above Four Mile Creek (SW ¼ Sec. 29, T1N, R9W).

655. Ten Mile Creek, about 0.1 mile downstream from bridge of Florida Highway 73 (NW ¼ Sec. 12, T1N, R10W).

708. At small waterfall on tributary to Ten Mile Creek, south bank, about ¼ mile downstream from bridge of Florida Highway 73 (NW ¼ Sec. 12, T1N, R10W).

709. South bank of Ten Mile Creek, about ¼ mile downstream from bridge of Florida Highway 73 (NW ¼ Sec. 12, T1N, R10W).

711. West bank of Chipola River, about ¼ mile up from mouth of Farley Creek (SW ¼ Sec. 12, T1N, R10W).

786. Ten Mile Creek, about 50 yards upstream from TU 196 or about ¼ mile upstream from bridge of Florida Highway 73 (NE ¼ Sec. 11, T1N, R10W).

787. Ten Mile Creek, south bank, about 1½ miles west of Chipola River (SE ¼ Sec. 12, T1N, R9W).

810. East bank of Chipola River opposite mouth of Taylor Branch (SW ¼ Sec. 17, T1N, R9W).

817. South side of Ten Mile Creek, large gully on the property of Mr. A. Sexton (1967) (SE ¼ Sec. 12, T1N, R10W).

818. Farley Creek, 0.1 mile west of bridge of Florida Highway 275 (SW ¼ Sec. 21, T1N, R9W).

820b. Farley Creek (lower beds), at bridge of Florida Highway 275 (SW ¼ Sec. 21, T1N, R9W).
821. Farley Creek, 0.1 mile east of bridge of Florida Highway 275 (SW ¼ Sec. 21, T1N, R9W).
824. Farley Creek, south bank about 0.5 mile east of bridge of Florida Highway 275 (SE ¼ Sec. 21, T1N, R9W).
825. Farley Creek at abandoned mill about ¼ mile west of bridge of Florida Highway 275 (SW ¼ Sec. 21, T1N, R9W).
827. Farley Creek, about ½ miles west of bridge of Florida Highway 275 (SE ¼ Sec. 20, T1N, R9W).
830. Ten Mile Creek at power line crossing, about one mile west of Chipola River (SE ¼ Sec. 12, T1N, R10W).
831. Ten Mile Creek (lowest Chipola beds exposed), slightly less than one mile west of Chipola River (SW ¼ Sec. 7, T1N, R9W).
949. Chipola River, west bank about 0.1 mile below power line crossing (SW ¼ Sec. 17, T1N, R9W).
950. Chipola River, west bank about 2000 feet above Farley Creek (SW ¼ Sec. 20, T1N, R9W).
951. Ten Mile Creek, about 1¼ miles west of Chipola River (SE ¼ Sec. 12, T1N, R10W).
998. Ten Mile Creek, about 1¼ miles west of Chipola River (SE ¼ Sec. 12, T1N, R10W).
999. Farley Creek, about 1000 yards downstream from bridge of Florida Highway 275 (SW ¼ Sec. 21, T1N, R9W).
1019. East bank of Chipola River, about 2000 feet downstream from power line crossing (NW ¼ Sec. 20, T1N, R9W).
1020. Small tributary (not shown on USGS topographic map) on east bank of Chipola River about ½ mile below power line crossing (NE ¼ Sec. 12, T1N, R9W).
1021. Ten Mile Creek, north bank, about 2200 feet east of bridge of Florida Highway 73 (NW ¼ Sec. 12, T1N, R10W).
1046. Agueguexquite Fm., roadcuts on both sides of Mexico Highway 180, 7.5 miles east of junction with side road into Coatzacoalcos, Veracruz, Mexico.
1050. West bank of Chipola River at power line crossing (SW ¼ Sec. 17, T1N, R9W).
1051. Ten Mile Creek, south bank, just downstream from large gully on property of Mr. A. Sexton (1967) (SE ¼ Sec. 12, T1N, R10W).
1052. Ten Mile Creek, north bank, just upstream from large dry cut-off meander (SE ¼ Sec. 12, T1N, R10W).
1095. Filisolo Fm., Mexico Highway 180, at west side of Arroyo Limon, 5 km west of San Andres Tuxtla, Veracruz, Mexico.
1097. Ten Mile Creek, south bank of recently (1972) cut-off meander, 500 yards east of Florida Highway 73 (NW ¼ Sec. 12, T1N, R10W).
1098. Ten Mile Creek, south bank, just below power line crossing (and just below TU 830) (SE ¼ Sec. 12, T1N, R10W).
1230. Cercado Fm., Rio Caña, east bank, bluffs just above the ford at Caimito on Los Quemados-Sabaneta road, Dominican Republic (=USGS 8532; Maury's Zone H).

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October 28, 1981

REVIEWS

EARTHLIKE PLANETS: Surfaces of Mercury, Venus, Earth, Moon, Mars, by Bruce Murray, Michael C. Malin, and Ronald Greeley. Published by W. H. Freeman Company, San Francisco, California, 1981, xv + 387 pp., illus. (some in color).

A synthesis of information gathered in the past two decades on the surface geology of Earth, the similar nearby planets, and the Moon, such as presented here is a worthwhile addition to the geological literature. The authors are quite well qualified to present an overview and analysis of these data. This work is quite well and pleasingly organized, the subject is definitively treated, and all parts are profusely illustrated with diagrams and actual photographs (many in color) of the planetary surfaces.

PALEONTOLOGY AND PALEOENVIRONMENTS, edited by Brian J. Skinner. Published by William Kaufmann, Inc., Los Altos, California, 1981, iv + 206 pp., illus. (some in color), $8.95

This is a new volume in the series *Earth and its Inhabitants*, consisting of reprints of articles published originally in *American Scientist*. This is one of the best of the volumes to appear thus far. It deals with a rapidly developing field of the geosciences and one that still requires considerable definition to enable earth scientists to appreciate properly its place in the study of the Earth.

This collection of reprints is highly recommended for student readings and for geoscientists interested in keeping abreast of progress in geology and paleontology.

—H.C.S.

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THE SPONGE FAUNA OF THE EOCENE CASTLE HAYNE LIMESTONE FROM EAST-CENTRAL NORTH CAROLINA

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I. ABSTRACT

The Eocene Castle Hayne Limestone has yielded one of the most varied and best preserved sponge faunas known from Tertiary rocks of North America, from outcrops near the community of Mt. Olive in east-central North Carolina. Demosponges include: *Ophiraphidites infundibuliformis* Schrammen, 1899; the new species *Ophiraphidites hadros;* and the new genus and species *Acrochordiella vokesi*. Hexactinellid sponges include the new lyssacinosid euplectelloid species, *Regadrella trabecula,* and the new dictyid *Haynespongia vokesae*. Fragments of root tufts and lychniscosid sponges also occur. This is the first report of lychniscosid sponges in North American Tertiary rocks.

II. INTRODUCTION

Fossil sponges are relatively rare in the Tertiary and Cretaceous rocks of North America. Although many units within the Gulf Coastal Plain and the Atlantic Coastal Plain contain dissociated spicules in some profusion, discrete identifiable fossil sponges are relatively unusual.

The sponge fauna described here is based upon collections from the Castle Hayne Limestone in south-central Wayne County, North Carolina. The Castle Hayne Limestone was named by B. L. Miller (1910, p. 674-675) for exposures near Castle Hayne in northern New Hanover County, near Wilmington, in the coastal section of southern North Carolina. The type section is approximately 60 miles south of the fossil locality.

Age of this formation has been somewhat controversial. T. W. Vaughan (*in* Miller, 1910) stated that fossils from the Castle Hayne Limestone were peculiar but recognizable as Jacksonian forms. Bryozoans of the fauna were monographed by Canu and Bassler (1920), and the larger invertebrate fossils were described by Kellum (1926). Canu and Bassler and Kellum agree in assigning the Castle Hayne Limestone a Jacksonian age, but Cooke and MacNeil (1952) concluded that it is of Claibornian age. Cheetham (1961) reworked some of the byozoan fauna and determined that the formation is unquestionably of Jacksonian age, as

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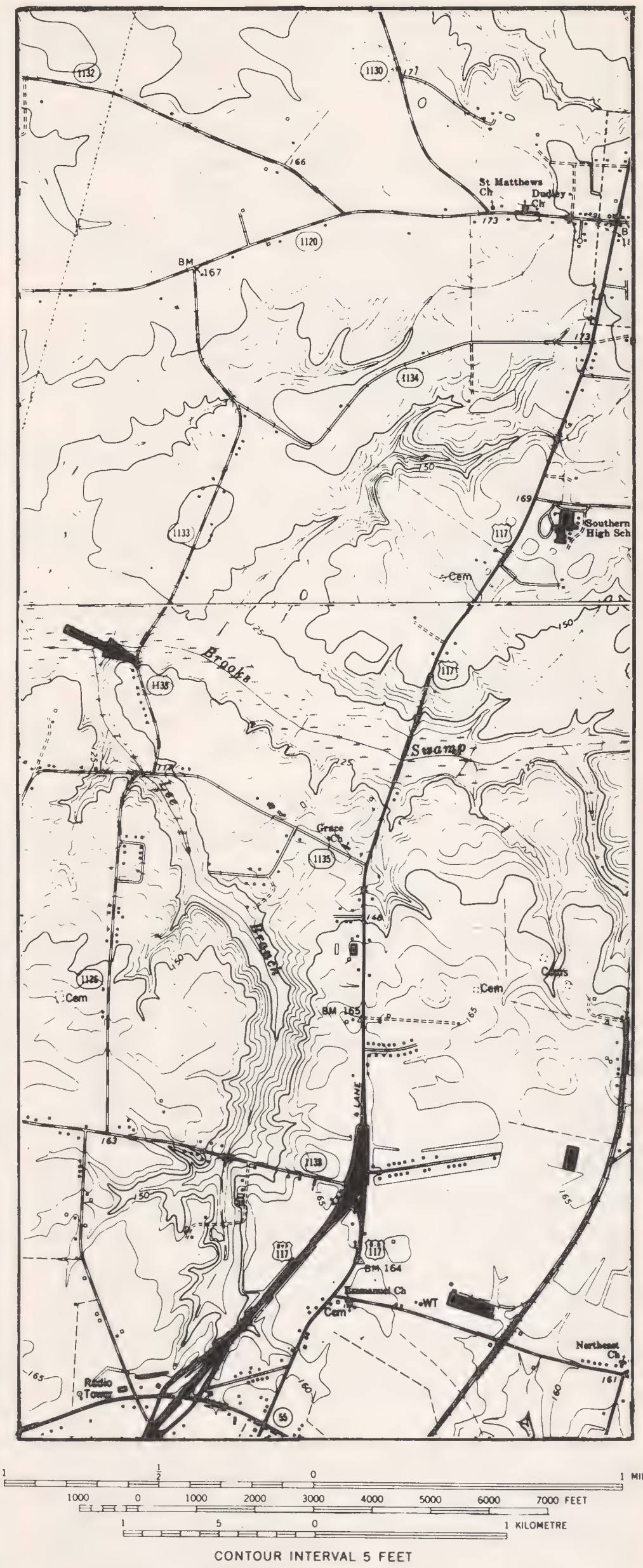
exposed in the classic localities of North Carolina.

In down-dip subsurface rocks, where the formation has been given a Claibornian age (Brown, 1958), the rocks appear to be definitely older, with the relationship most easily explained as an updip onlap, as suggested by LeGrand and Brown (1955). Stuckey and Conrad (1958, p. 44-45) show the unit as middle and upper Eocene. They apparently included within the Castle Hayne Limestone rocks that initially had been mapped as Castle Hayne Limestone as well as the Trent Formation of older maps. These two units now appear to be of roughly equal age, but of differing facies.

All the fossils described in the present paper came from a single locality in the upper Eocene (Jacksonian) Castle Hayne Limestone, Tulane University locality TU 869, collected by Harold and Emily Vokes. This locality is on the south side of Brooks Swamp (see Index map) in roadcut south of the bridge, 2.1 miles (3.4 km) southwest of Dudley and 3.6 miles (5.8 km) due north of the center of the community of Mount Olive; at 35°14′40″ N and 78°04′13″ W (3904300 N — 766650 E, Zone 17, Universal Transverse Mercator) on the Mount Olive, North Carolina 1:24,000 7.5 minute topographic quadrangle. The locality is reached by travelling northward on U.S. Highway 117 for 3.0 miles (4.8 km) from the center of Mount Olive, then west-northwestward 0.8 miles (1.3 km) along State Route 1135 and then north-northwestward 0.4 miles (1.0 km) along State Road 1133 to the south bridge cuts.

The locality has since been destroyed by road construction and the isolated outcrops covered by fill. When the initial collections were made, the sponges occurred in a weathered red clay. The stratigraphic position of these outcrops within the Castle Hayne Limestone is not known because of the isolated position of the outcrop. The sponges occurred largely free of matrix as a weathered lag.

The sponges were washed to remove the clay matrix and were further cleaned in the laboratory by short treatment in an ultrasonic vibrator cleaner with warm soapy water. Some isolated specimens were also treated with dilute hydrochloric acid but with little effect. For photographs, specimens were painted with black fountain-pen ink and then coated with sublimated ammonium chloride.



Map showing location of TU locality 869, Wayne Co., North Carolina.

III. ACKNOWLEDGMENTS

Appreciation is given to Harold E. and Emily H. Vokes for loan of the collection and for review of various drafts of the manuscript. Study of the collection was done while on a research leave from the Department of Geology, Brigham Young University.

IV. SYSTEMATIC PALEONTOLOGY

Class DEMOSPONGEA Sollas, 1875
Order CHORISTIDA Sollas, 1888
Family CEPHALORAPHIDITIDAE Reid, 1968

Reid (1968, p. 1252) proposed the Cephaloraphiditidae to include the triaene-bearing sponges included by Schrammen (1903) in the Ophiraphiditidae, thus presumably including the several fossil species of *Ophiraphidites* per Schrammen, *Cephaloraphidites*, *Polytretra*, and *Megaloraphium*, but excluding *O. tortuosus* Carter (1876, p. 458) and *Heteroraphidites* Schrammen 1901 (=*Allioraphium* Schrammen, 1910). When Schrammen (1903, p. 17; 1910, p. 119) proposed and expanded the Family Ophiraphiditidae, he placed it in the then recognized Order Tetraxonia, but was uncertain as to which suborder it belonged because microscleres of the sponges were not known. De Laubenfels (1955, p. E-43) placed the family in the Order Choristida, presumably based upon the occurrence of long shafted triaenes in the skeletal net and of smaller triaenes as dermal spicules in the several genera included. Reid (1963) constructed a classification of Demospongea that updated Schrammen's work (1910, 1924) but still left those sponges whose spicules are ophirhabds, among others, in uncertain ordinal position.

The family Ophiraphiditidae was based by Schrammen (1903, p. 17; 1910, p. 119) on the recent genus *Ophiraphidites* Carter, 1876. The type species of the genus, *O. tortuosus* Carter (1876), was based on macerated fragments containing only ophirhabds. Schrammen (1910, p. 119) emended the generic description to include variously shaped sponges in which the main skeleton consists of matted ophirhabds but also includes straight or slightly bent oxeas, and which have triaene dermalia that have unfolded rays. Reid (1968, p. 1252) pointed out that ophirhabds occur in several modern sponges and erected the Family Cephaloraphiditidae to include these sponges with triaenes.

Cephaloraphidites Schrammen (1899, p. 6; 1910, p. 124) is separated from several fossil species of *Ophiraphidites* by possessing common club-shaped styles, in addition to the matted ophirhabds, oxeas, and dermal triaenes.

OPHIRAPHIDITES INFUNDIBULIFORMIS Schrammen, 1899
Plate 1, figs. 1, 3, 5, 6; Text-fig. 1

Ophiraphidites infundibuliformis SCHRAMMEN, 1899, p. 5, pl. 1, fig. 4, pl. 2, fig. 6; SCHRAMMEN, 1910, p. 121-123, pl. 14, fig. 7, text-fig. 7, fig. 5; DE LAUBENFELS, 1955, p. E43, fig. 22.

Diagnosis: Wavy, ear-shaped to palmate or irregularly conical to conico-bylindrical sponges composed of matted irregularly curving ophirhabds, coarsest in gastral part of wall. Gastral and dermal layers a felt of small smooth-rayed triaenes. Canals labyrinthic with cross-connecting radial, concentric-horizontal and vertical to inclined series.

Description: Irregularly wavy, ear-shaped, to flat or irregularly conical to conical-cylindrical sponges and fragments are in the collection. Walls range up to 12 mm thick but are only 5 to 6 mm thick in most fragments. Numerous canal openings are somewhat aligned, on both exterior and interior surfaces.

The sponge wall is composed mainly of matted, intertwined, irregularly curving to nearly straight ophirhabds, with dermal and gastral layers of small triaenes. Ophirhabds are gently to strongly curved and recurved monaxons that taper evenly to sharp tips (Text-fig. 1-J, K, T). Some are irregularly wavy, others are serpentine, and others are hooked to almost circular. These spicules are up to 0.08 mm in diameter and 2 mm long, with most ophirhabds in the interior of the wall 0.04 to 0.06 mm in diameter at midlength and 1.0 to 1.5 mm long. Strongly curved spicules are particularly common near the gastral and dermal surfaces or in the vicinity of the canals; nearly straight spicules are concentrated in the linear tracts between aligned series of canals. This relationship is best seen on outer parts of the wall where, on some specimens, there is an upward and outward fanning of bundles of generally less strongly curved spicules.

Gastral surfaces are layered with a dominance of coarse ophirhabds. Finer spicules dominate in the main part of the wall and on the dermal surface. Gastral ophirhabds are up to 0.08 mm in diameter and nearby main wall and dermal ophirhabds are generally 0.04 to 0.06 mm or less in diameter.

One triaene (orthotriaene) seen in the gastral surface of a large conical irregularly wavy fragment has smooth, unbranched, small rays approximately 0.2 mm long, with basal diameters of 0.06 mm. These are bent forward about 10 to 15 degrees and taper evenly and smoothly to pointed tips. The longer shaft is buried within the sponge wall and is of unknown total length.

The gastral layer is a felt of varying thickness that grades from the almost exclusively ophirhabd interior of the wall, out through interlayered rare to common small triaenes, to a gastral-most layer of almost exclusively small triaenes. This gradation takes place through 1 to 2 mm of wall thickness. These small triaenes (Text-fig. 1-N, P) are arranged with one proximal and three paratangential rays. Paratangential rays are most evident on weathered surfaces. They are oriented 120° apart from their junction and are bent foreward only slightly to as much as approximately 20 degrees. Rays on the spicules are smooth, unbranched, and gently taper to a sharp point. They range up to 0.14 to 0.16 mm long and have basal diameters of 0.02 to 0.03 mm. The most common triaenes are smaller, with tangential rays approximately 0.10 mm long and basal diameters of approximately 0.01 mm. Many triaenes are much smaller, however, and some with ray lengths of only 0.02 to 0.03 mm are common and well preserved.

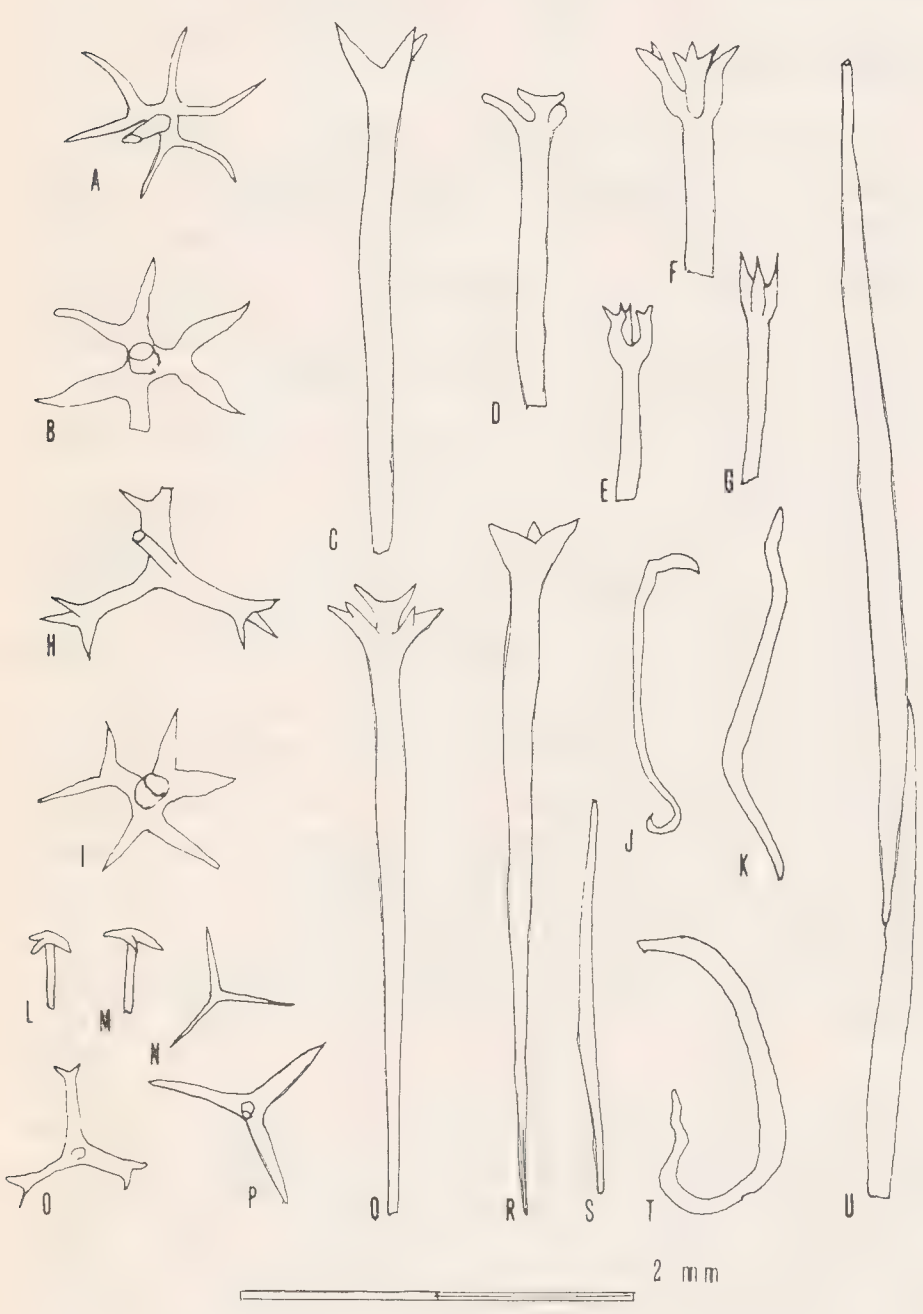
There is a general pattern within the dermal layer for one tangential ray of the triaenes to be subparallel to the long axis of the adjacent canal series or the major skeletal bundles. Such a pattern is most evident for the larger triaenes, and obscure for smallest spicules. There is no layering nor size gradient visible in the distribution of gastral triaenes but all fit into an irregular, matted, felt-like layer.

The dermal triaene felt is composed of spicules of similar size and distribution. The layer is thickest on crests of main ophirhabd bundles, between canals, and there the triaenes obscure the large spicule pattern.

A few long, smooth, sharply pointed oxeas occur throughout the sponge. They are most common in association with the nearly straight ophirhabds in the main upward fan-like bundles. but occur elsewhere and at other orientations, as well. They are up to 4 or 5 mm long and 0.10 to 0.12 mm in maximum diameter. Most are of the same general dimensions as the associated ophirhabds and possibly grade into them, through increased curvature and irregularity.

Largest canal openings on the coarsely spiculed side of the walls, are spaced from 1 to 4 mm apart, but most are spaced 1.5 to 2.0 mm from center to center. Five to seven such ostia occur per 5 mm square. Small canal openings are separated by approximately 0.5 mm of skeletal net and are relatively uniformly spaced. There are 30 to 40 of the small openings per 5 mm square.

Internally canals are labyrinthic with radially-oriented outer segments that open onto the dermal or gastral surfaces. These labyrinthic canals are connected by horizontal canals, which meander somewhat, but maintain a concentric pattern in the wall of conical forms. In addition, vertical to steeply inclined, meandering to straight slit-like canals occur in the wall interior. These are somewhat aligned in areas where the spicules are bundled prominently. In areas where the sponge is sharply bent the canals form more linear and elliptically opened series. In one area, considered to be typical, slit-like, elongate, elliptical openings occur in a series between bundled nearly straight spicules. These bundles occur eight in 5 mm, measured horizontally. The intervening canals range from only 0.2 to 0.5 mm wide, with most being 0.2 to 0.3 mm across. Canals are spaced four to six per 5 mm in the



Text-figure 1. Spicules of *Ophiraphidites infundibuliformis* Schrammen, 1899. A, B, I, O. Dichotriaenes, in large part from the gastral or dermal layers. C-G, Q, R. Protriaenes, some with simple rays and others with modified secondary rays. H. Modified dermal triaene with three secondary rays on each of the paratangential rays. J, K, S, T. Ophirhabds of the main skeletal net showing variations in curvature and size. L-N, P. Simple small orthotriaenes from the gastral or dermal net. U. Large oxeas from a main spicular bundle in the main wall.

beam-bound series. They also emerge at an acute angle to the surface, producing an apparent lenticularity.

Elsewhere on the same specimen, opposite the canal pattern measured on the larger spiculed side, the canals are circular and range from 0.3 to 0.6 mm in diameter, with most approximately 0.4 mm across. They are uniformly spaced and separated by 0.3 to 0.6 mm of skeletal material. None of these radial canals extends through the wall, but most extend to near midwall where radial horizontal concentric and steep rising canals interconnect.

Concentric horizontal canals are circular to strongly elliptical, parallel to the skeletal bundles. Canals are 0.3 to 0.5 mm across, up to 0.8 mm high, and are concentrated in the middle third of the wall. They cross-connect the radial canals and the steeply rising series in a somewhat labyrinthic fashion. It is far from a uniformly spaced subrectangular pattern in most areas, but approaches such an arrangement in the sharply folded regions where the skeletal tracts are most linear.

In cross sections of the sponge wall, the horizontal concentric canals and the rising fanning canals are spaced approximately 1.0 mm apart, measured horizontally parallel to the radial series. The concentric canals are spaced approximately the same distance apart, vertically, although they are quite irregular.

A series of upward and outward fanning canals is seen in some of the sponge fragments, and is particularly well developed in the thicker walled specimens. These canals are slit-like to circular, approximately 0.3 mm across, and are parallel to the tracts of nearly straight spicules. They are most prominent in the two-thirds of the wall closest to the finer spiculed and more linear spiculed surface, whether gastral or dermal is at present a question. They cross-connect with the radial and concentric series and are less labyrinthic than either because of their position between the ascending and fanning spicule tracts. They are not uniformly developed, however, and they are loci of crushing in those specimens that have been flattened during fossilization.

One specimen of the thin, blade or ear-like form shows the surface sculpture and canal pattern well. The coarse-spiculed side is marked by obscure rings where the large canal openings are common. These canals slope inward (or down) and distally to the radiating patterns of the spicule tracts on the other side. The bands or areas of concentration are 10 to 15 mm apart, radially, and are normal to the radiating tracts. Intervening areas are perforated by the smaller canal openings.

The reverse side is the part of the wall with finer ophirhabds and is the part that best shows pinnation of the spicule tracts. Tracts expand distally and new tracts are inserted as the net expands.

A few rare club-ended spicules are present near the gastral (?) surface on some fragments. One such spicule is broken but has a diameter of 0.11 mm along the short staff fragment, expanding abruptly to a spherical knob-like termination 0.14 mm in diameter; both spicule parts are smooth. These very rare spicules are like the amphistyles in *Allioraphium spongiosum* Schrammen (1910, p. 122, fig. 7-40), or more club-shaped tips of styles of *Cephaloraphidites milliporatus* Schrammen (1910, p. 124-125).

Discussion: In all respects the many fragments of the species in the North Carolina collection agree with the type material described by Schrammen (1899, p. 5; 1910, p. 121-123) from the Upper Cretaceous of Northern Germany. Even the siliceous preservation appears strikingly similar. The North Carolina specimens commonly encrust dictyid sponges and are themselves rarely encrusted. This suggests a relatively loose dermal layer for the species or else the fragments were buried early in the ontogeny of the sponge so that epizoic or epiphytic organisms could not become attached. The associated dictyid sponge fragments are intensely overgrown. In a few instances fragments of *Ophiraphidites* are encrusted by cheilostome bryozoans, but rarely are sponges or other organisms, other than possible worm tubes, attached to these irregularly spiculed forms.

Ophiraphidites infundibuliformis has characteristically overgrown the associated dictyid sponges indicating that the latter were the primary colonizers. In addition, worm tubes and lychniscosid sponges have encrusted *Ophiraphidites* and *Acrochordiella.*

Figured specimens: U. S. National Museum 252484 to 252487.

OPHIRAPHIDITES HADROS n. sp.
Plate 1, figs. 7, 8; Text-fig. 2

Diagnosis: Massive cavernous sponges composed of crudely bundled, curved to serpentine ophirhabds and rare oxeas, with dermal layer of matted, smooth-rayed small triaenes. Surface with round ostia or slits or upward-radiating or cross-connecting horizontal canals.

Description: One large sponge and two small fragments are in the collection. The large specimen, the holotype, is a coarse textured, cavernous sponge, now approximately 80 mm high and 55 mm across, with a broken base but almost complete upper part. it has a rough, almost clinker-like, exterior that is marked by several vertically elongate openings, over 10 mm across,

and by numerous, more or less equally spaced, openings 2 to 5 mm across, which are distributed over the entire sponge surface. The large openings probably functioned as major excurrent openings. One, 5 × 12 mm in cross section, penetrates deep into the sponge, but is open above. Elsewhere, moderately uniformly spaced openings, 2 to 5 mm across, occur in slits 5 to 8 mm high. They are spaced 5 to 10 mm apart and probably functioned as large excurrent openings.

Numerous canals, approximately 1.0 mm in diameter, meander through the massive, somewhat pillared sponge body. They mark open or loosely spiculed areas between the skeletal tracts, which appear to fan upward and outward. Openings of these canals widen near the surface and produce the rounded to elongate depressions that are scattered over the sponge surface. These canals are irregularly developed as horizontal cross connections, as well, even near or at the exterior of the sponge.

Smaller openings, 0.4 to 0.5 mm in diameter, are also common on the exterior and interconnect with the intermediate-size canals and the larger excurrent openings. These smaller canals generally open into the meandering, impressed, surficial depressions, as do the larger canals, but a few of the smaller ones also open on the crests and flanks of the intergroove ridges.

The surficial grooves are rounded and 1 to 2 mm across and 2 to 3 mm deep. They meander and anastomose irregularly, but generally with a vertically elongate trend. Ridges between the grooves are also rounded and mark the emergence of spicule bundles.

Spicules are ophirhabds, triaenes, and oxeas (Text-fig. 2). Ophirhabds are wavy to strongly curved or irregularly serpentine spicules that may blend in a variety of planes. They are smooth and taper to sharp points or rounded tips at both ends, are smoothly to irregularly curved around canal openings and over rounded surfaces, and are most regular in the central parts of closely packed spicule bundles. Ophirhabds are most irregular in surficial areas where adjacent spicules have least interferred with them. They are mostly 0.08 mm in maximum diameter and up to 5.0 mm long. Smaller spicules, up to 0.06 mm in diameter, are locally common particularly on the tips of the bristled spicule bundles on the upper part of the sponge. These may be immature ophirhabds.

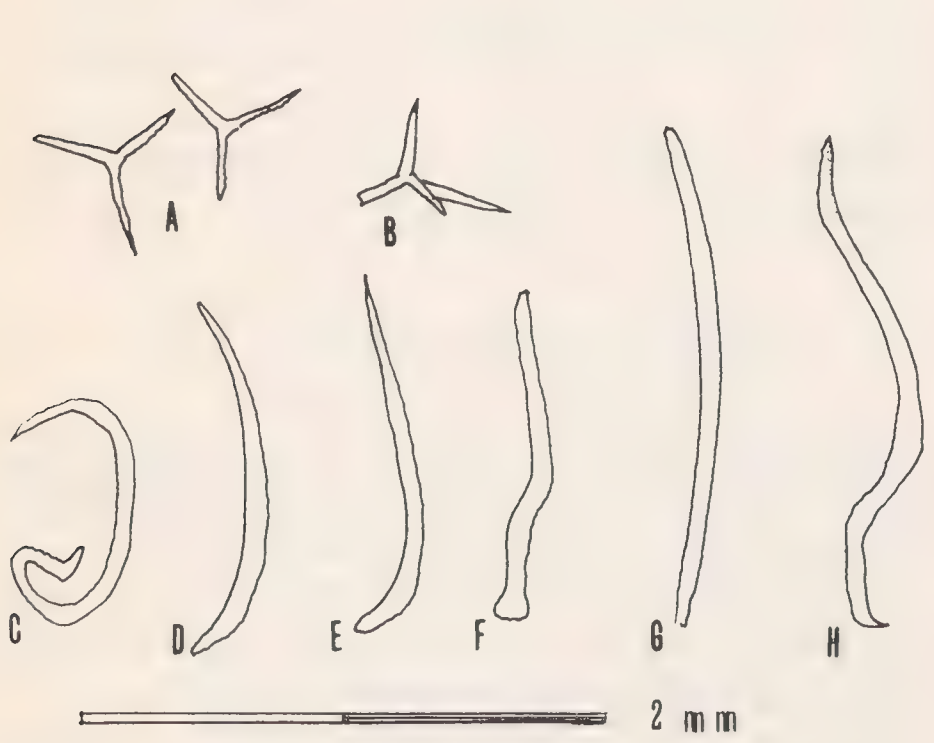
Oxeas are not common but are scattered throughout the sponge as slightly larger spicules, with maximum diameters of 0.14 to 0.22 mm. They are smooth, gently doubly tapering, and have pointed tips, and are inserted at various angles within the net. Some may be overgrown foreign spicules since, in two cases, foreign oxeas are inserted into large canal openings on the surface.

Triaenes are not common within the main matted skeletal net, but are moderately common in tips of the spicule bundles and on crests of irregular ridges and appear to be principally dermal. Their preservation, mainly on the elevated regions, may be related to a possible cortex. Triaenes are most common where tightly matted to one another or infilling open spaces between outer ophirhabds. They thus produce dense areas of the skeletal structure. These small dermal spicules have three equally spaced, paratangential rays, have diameters up to 0.04 mm, and are up to 0.75 mm long. Most of these spicules are less than half that size, however, with ray lengths of less than 0.3 mm and diameters of less than 0.03 mm.

A few larger triaenes occur in the main skeleton and are of the same general dimensions as the ophirhabds. For example, one well preserved spicule has three tangential rays 0.12 to 0.14 mm in diameter and 1.4 to 1.5 mm long. These rays are bent slightly distally, are pointed and unbranched, and taper uniformly from their junction with the proximal ray, which is embedded in the skeletal net.

Acid-etched residues from the sponge include two anatriaenes, two loose hexactines, and one dichotriaene, in addition to wavy smooth oxeas and equirayed triaenes. The dichotriaene, hexactine, and anatriaenes are common in associated hexactinellids and are probably foreign to the present species.

Vertical spicule bundles are generally 0.7 to 1.2 mm in diameter, are irregular vertically, and are cross-connected at irregular intervals, generally less than 1 mm, by sub-horizontal bundles, by bifurcation, or by merging with lateral bundles.



Text-figure 2. Spicules of *Ophiraphidites hadros*, n. sp. A. Simple orthotriaenes from the dermal layer. B. Simple protriaene from the dermal net. C-H. Ophirhabds from the main skeletal net showing size and variation in curvature.

Discussion: Schrammen (1899, 1910) defined various genera now included in the

family Ophiraphididae on the basis of spicule structure. He included within the genus *Ophiraphidites* (Schrammen 1910, p. 120) those forms that have skeletons of ophirhabds and straight or slightly bent oxeas, with dermal layers of triaenes with unbranched rays. *Cephaloraphidites* (Schrammen, 1910, p. 124), in addition, contains club-shaped styles. *Heteroraphidites (=Allioraphium)* (Schrammen, 1910, p. 125-126) is composed of ophirhabds but includes large tylostyles, amphistrongyles, tylotes, and oxeas.

Polytretia (Schrammen, 1910, p. 126) and *Megaloraphium* (Schrammen, 1910, p. 127) are flattened, ear-shaped sponges with large canals and skeletons of matted ophirhabds, triaenes, and oxeas. These genera differ from *Ophiraphidites* mainly in their canal structure, size of their small main spicules, and in lacking coarse triaenes.

Schrammen added *Ophiodesia* (1936, p. 183) and *Euleraphe* (1936, p. 184) to the family. *Ophiodesia* has matted sinuous ophirhabds and lumpy styles while *Euleraphe* has thin short, eulerhabd spicules, as in *Megaloraphium*.

Based upon spicule patterns, the North Carolina specimen belongs in the genus *Ophiraphidites* but differs from other described species in its massive growth habit. *O. infundibuliformis* Schrammen (1899, p. 5; 1910, p. 121, 123) is funnel, club, or irregularly shaped and differs in being much less massive, even in areas that are somewhat folded.

Ophiraphidites tuberosus Schrammen (1899, p. 5; 1910, p. 124; pl. 18, fig. 8) is perhaps the most closely related species in its irregular growth but has triaene dermalia with tangential rays that are bent backward rather than forward like in the present species. In addition, *O. tuberosus* is much less massive, and lacks the sculpture, the clustered tracts, and the large openings that are typical of the North Carolina species.

Ophiraphidites cylindricus Schrammen (1910, p. 121), *O. annulatus* Schrammen (1910, p. 120-121), and *O. ramosum* Schrammen (1910, p. 123-124) are all simple or forked ramose, tubular sponges and much different in general growth form from the North Carolina species.

Type material: Holotype USNM 252488, paratypes BYU 1540 and 1541.

Etymology: Hadros, Latin, bulky, stout, thick, referring to the relatively massive form of the species.

Order LITHISTIDA Schmidt, 1870
Suborder TETRACLADINA Zittel, 1878; emended Sollas, 1887
Family ACHROCHORDONIIDAE Schrammen, 1910

Achrochordonia Schrammen (1901, p. 96) was the only genus included in the Achrochordoninae when it was first proposed by Schrammen (1910, p. 96) as a subfamily in the then Family Tetracladina. Tetracladina in this sense of Schrammen are those sponges whose skeleton is composed of spicules with four rays, which are bound together by zygosis. Dermalia in the group are triaene-based, or rare anaxial siliceous fragments or plates. De Laubenfels (1955, p. E52) considered the Tetracladina as a suborder of the Lithistida and included in that suborder sponges with tetracrepid desmas that unite with adjacent spicules at elaborately sculptured ray extremities.

Schrammen differentiated the Achrochordoniidae from other tetracladinid sponges on the basis of the family having modified dermalia and on the warty nature of the tetraclone spicules. The Achrochordoniidae contain only dichotriaene dermalia and, as such, differ from most of the other tetraclad sponges with heavily nodose or warted tetraclones. In general, other forms have phyllotriaenes, discotriaenes, or other modifications of triaenes as dermalia. Until now only a single genus, *Achrochordonia* Schrammen, 1912, has been included in the family. Two species of that genus were both described from the Quadraten Kreide near Oburg, where both were indicated to be relatively rare.

ACHROCHORDIELLA, n. gen.

Diagnosis: Massive, lobate to digitate, anastomosing to branched, finger-like sponges. Principle skeleton of small to medium sized, warty, tetraclones. Dermalia of characteristic dichotriaenes or modifications of dichotriaenes that may have lost one or two primary or secondary branches. Phyllotriaenes rare. Surfaces marked by moderately indented strong, somewhat anastomosing, generally nearly vertically oriented canals. Individual branches without spongocoel and relatively dense.

Discussion: Achrochordonia Schrammen, 1901, is a closely related genus but differs from *Achrochordiella* principally in the character of the triaene-based dermal spicules. *Achrochordonia* Schrammen (1910, text-fig. 6-7, 10) is shown with dermalia that are clearly simple, radial, dichotriaenes in which the secondary rays of the main rays branch at uniform angles and appear to be moderately consistant and uniformly developed. In addition, the main skeletal tetraclones are somewhat more irregular and have warts or tubercules that consistantly have larger diameters, relative to the main axis, than in *Achrochordiella*. Both genera, however, are of the same gross shape with relatively massive bases, from which extend rounded, pointed, or club-shaped branches, or with bulbous to rounded lobate masses that project from the general surface. In general, the North Carolina genus is distinctly more branched and certainly has a more sculptured appearance produced by the indented short, tangential canals.

Plinthosella Zittel (1878, p. 153), *Pycnodesma* Schrammen (1910, p. 115), and related forms, have similar, warty, tetraclad spicules, but differ significantly in possessing an array of decidedly different dermal triaenes.

Type species: Achrochordiella vokesi, new species.

ACHROCHORDIELLA VOKESI, n. sp.
Plate 3, figs. 1-3, 5; Text-fig. 3

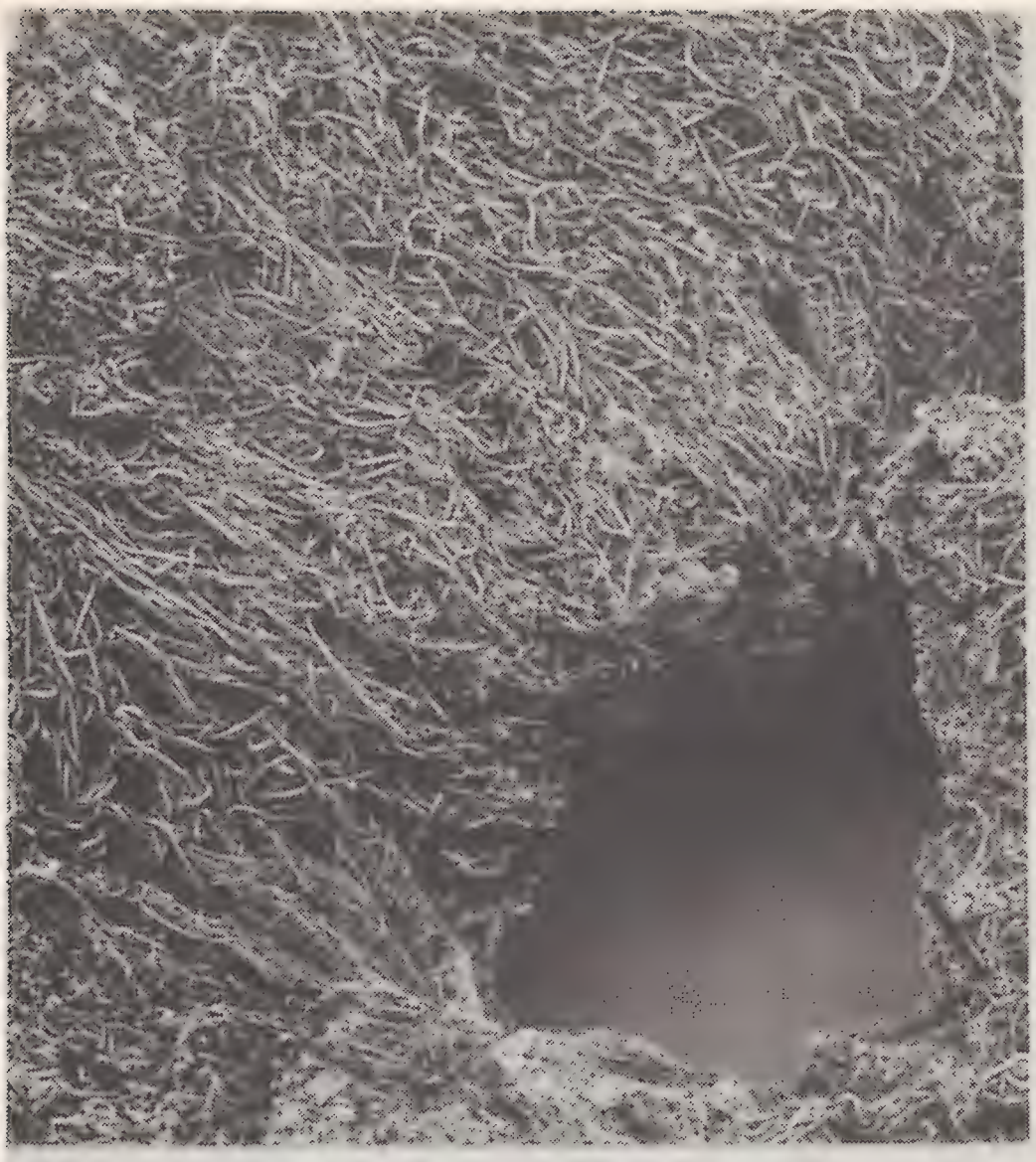
Diagnosis: Digitate to arborescent sponges, with earlier parts fused and enlarged by lateral growth of individual branches and increase in diameter. Major excurrent canals developed between fused branches are largest canal openings. Relatively massive and dense skeleton of fused, knobby or warty tetraclones. Sculpture particularly prominent on distal surface of spicules, but evident on practically all surfaces. Dermalia dichotriaenes or dichotriaene-based spicules in which a secondary ray aborted to produce a secondary pentactine commonly with irregular wavy or bent rays. Other tetraxonic-based spicules, such as smooth-rayed tetraxons may occur. Surface marked by more-or-less continuous to anastomosing vertical canals impressed into the sponge surface. These are bridged in interior of digitations and function as major excurrent canals without producing porous zones in branches.

PLATE 1

Ophiraphidites and *Regadrella* from Eocene Castle Hayne Limestone

FIGS. 1, 2, 5, 6 — *Ophiraphidites infundibuliformus* Schrammen, 1910. *1,* Photomicrograph of the gastral surface of a plesiotype, USNM 252484, showing the relatively coarse nature of the skeletal net, the somewhat bundled occurrence of the spicules, slit-like canals that penetrate the sponge wall, and dense areas where the fine dichotriaene-based dermal spicules are preserved. ×5. *2,* Photomicrograph of a plesiotype surface showing characteristic curved ophirhabds and irregularly spaced and arranged circular canals that feed more or less radially through the sponge wall. Dense areas are composed, in large part, of tiny dichotriaenes of the dermal and gastral layers. ×5. USNM 252485. *5,* Ear-shaped fragment of a plesiotype showing irregular folding and thickness of one of the walls, as well as the distinctly aligned canals that parallel the bundled spicules of the wall. Cross section of the sponge wall in the lower left shows the generalized upward radiating canal pattern. USNM 252486. Natural size. *6,* Somewhat tubular fragment of the sponge showing the irregular growth form, wall thickness, and irregular arrangement of various canals on both the interior and exterior. Natural size. USNM 252487.

FIGS. 3, 4 — *Regadrella trabecula,* n. sp. Holotype, USNM 252492. *3,* Photomicrograph of the skeletal net showing the compound beam-like architecture of the sponge, where subparallel hexactine-based spicules are laterally fused into beams by a synapticular web or by cross-bracing synapticulae, with somewhat bundled spicules separating the moderately large canals. ×5. *4,* View of the holotype fragment showing the relatively coarsely canaled architecture and the bundled, beam-like, skeletal net characteristic of the species. Weak ribs show as densely spiculed areas in the lower part of the sponge and appear to represent former oscular margins. These dense layers are composed of short-rayed spicules and synapticulae, with limited development of the compound beams. Natural size.



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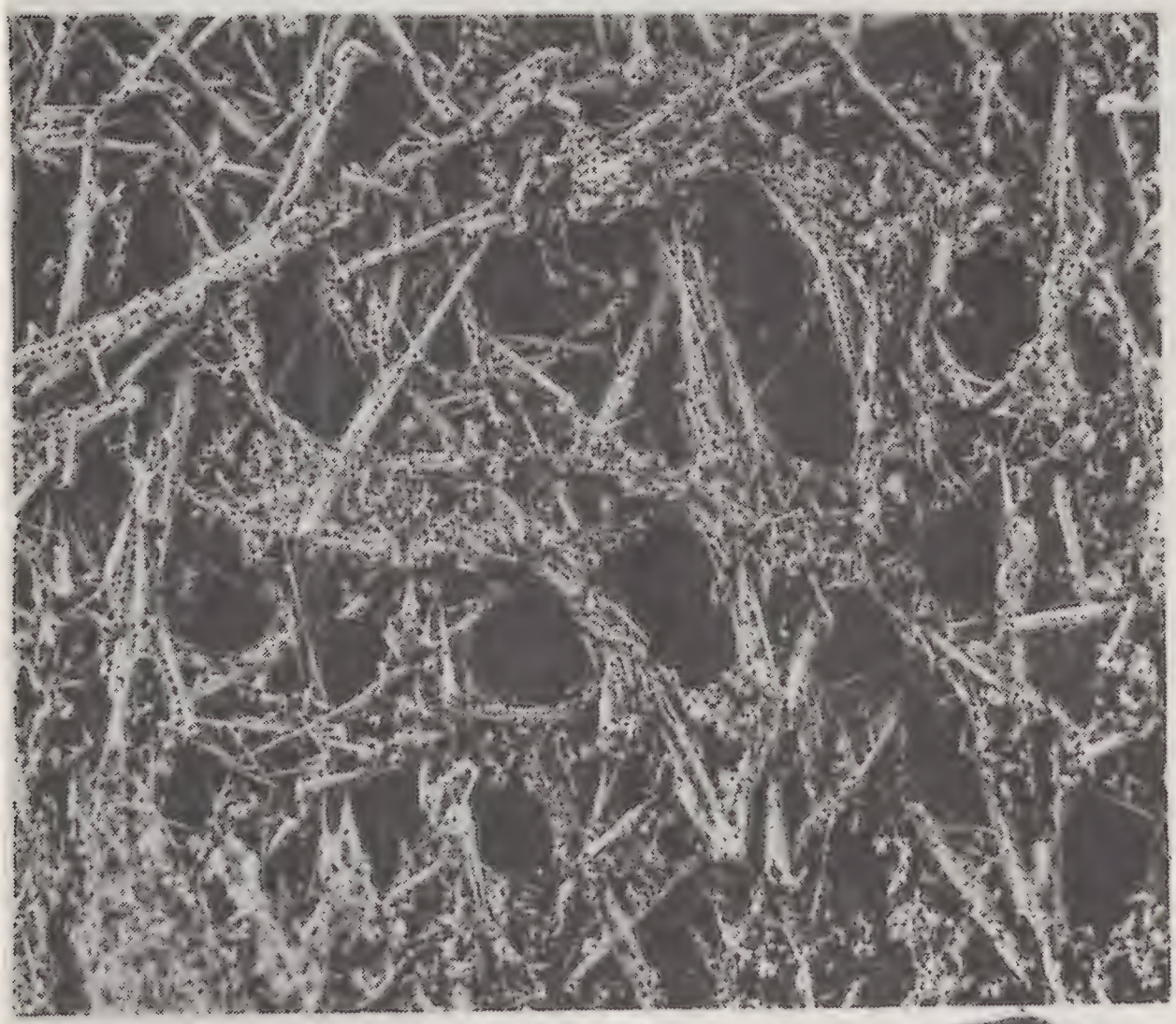

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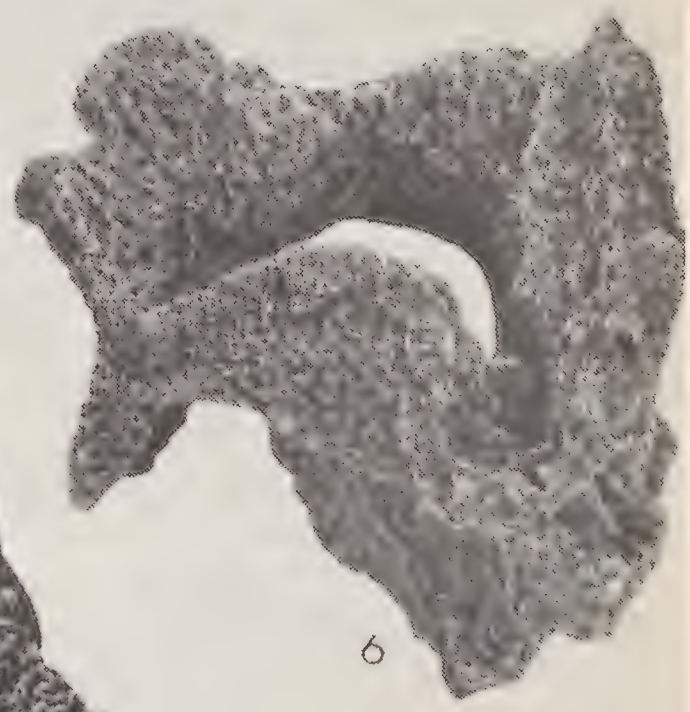

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PLATE 1

Description: Fragments of individual sponges are up to 105 mm tall and form masses up to 90 mm wide. These are upward arborescent or branched sponges with the massive, basal part of the sponge having individual lobes or branched growths several millimeters across. Each individual lobe terminates in a series of branches that diverge at 60° to 70° from the main axis of the lobe. The lateral branches may merge with adjacent major stalks in the lower part of the sponge. Secondary branches, from 10 to 20 mm across, tend to be circular in section, but those that are larger than this tend to be flattened elliptical or flattened irregular in section. The entire growth produces an interlocking, interbraced, anastomosing colony in the lower part and a sharply branched and digitate to arborescent appearance in the upper part of the sponge. The form lacks a spongocoel or a pronounced zone of excurrent canal development along the central axis of the sponge. Excurrent and incurrent canals are moderately uniformly distributed throughout the massive skeleton.

Surfaces are marked by a series of pronounced, uniformly indented, tangential canals that rise approximately vertically, although somewhat anastomosing to arborescent. Individual canals range from 1.0 to 1.4 mm in diameter, with most 1.0 to 1.2 mm across. Where most pronounced, individual canals are separated by 1 mm or less. Commonly only 0.3 to 0.5 mm of skeletal material intervenes where the system is best developed. Individual canals are traceable, vertically, for from only a few mm to 30 or 40 mm, where they lose their identity and are replaced in *en echelon* fashion by other somewhat meandering surficial canals.

Canals of the interior are somewhat irregularly placed. Main excurrent canals appear to be only former surficial canals that have been bridged over during growth. These formerly surficial canals become major excurrent features of later parts of the interior, or are filled in, because the interiors of the sponge branches, where broken across, show only a few moderately large, 1 mm and above, canals. The interior of the sponge is perforated primarily by irregular anastomosing skeletal openings and minor canals, 0.5 mm across or finer. These have no predictable pattern, or orientation, but merely appear to form a very complex interconnected system that, with the irregularity of the skeletal net, tends to form a massive, uniform, yet unpatterned sponge.

The somewhat pointed tips of individual branches are marked only by the impressed semi-circular canals converging toward the tip. There are no clusters of major excurrent canals visible at the tip nor in any of the broken branches. There is a weak tendency toward radial arrangement of skeletal openings and canals but there is no clearly defined transverse nor longitudinal system on the branches, other than the surficial, impressed, U-shaped openings.

The principal skeletal net is composed of small to medium-sized, warty, tetraclones (Text-fig. 3-H, I, M) that are generally arcuate or convex toward the distal surface of the sponge. Individual tetraclones may unite tip to tip, but commonly have complex arborescent ray tips fused to the sculptured back or distal surface of the curved spicules. Generally speaking, the distal ray is aborted to a knob, or wart, of the same general proportions as those that mark the distal surfaces of the various clads. The skeletal net is firmly fused by zygosis of these complex arborescent ray tips to adjacent spicules.

Clads of the main tetraclones are 0.2 to 0.3 mm long. They have a relatively small diameter from near the clad junction to the beginning of the arborescent expansion of the ray tips. The inner, moderately smooth, subcylindrical to elliptical part of the ray is approximately 0.2 mm long in the largest main body spicules. The ray extends beyond this an additional 0.10 to 0.15 mm, to where the arborescent tip flares markedly to articulate with the adjacent spicule surfaces.

In their thinnest part the main large-bodied spicules are 0.08 to 0.10 mm across. Diameter increases to approximately 0.12 to 0.14 mm at the ray junctions, and up to 0.15 mm across the many arborescent branches at the articulation.

Surfaces of the main body spicules are covered by rounded, hemispherical, warts, or nodes, that are somewhat irregularly placed, although of remarkably uniform size. These warts range from 0.025 to 0.030 mm across in the large body spicules. They are almost perfectly hemispherical, and are packed side-by-side over much of the lateral and distal surfaces of the spicules. They tend to be more widely and irregularly spaced on proximal parts of the spicules.

Considerably smaller warty tetraclones occur in the outer and dermal parts of the branches. These are particularly evident on one of the paratypes, where these well-defined spicules have rays 0.15 to 0.20 mm long and only 0.06 to 0.08 mm across. These more delicate spicules have well-defined arborescent ray tips, some with a significant expansion. After narrowing to 0.04 to 0.05 mm across, rays subdivide into small branches, 0.02 to 0.04 mm across, that articulate with the distal surfaces of the adjacent delicate spicules. In general, these fine spicules have nodes 0.010 to 0.025 mm across, which are locally arranged in almost ringlike patterns although on most spicules they are irregularly spaced, as in the larger spicules.

There is apparent gradation from relatively small spicules in the outer part of the branches, to large spicules in the inner part of the branches and the main mass of the skeleton. Some of this apparent gradation may be related to enlargement of individual spicules during growth, so that

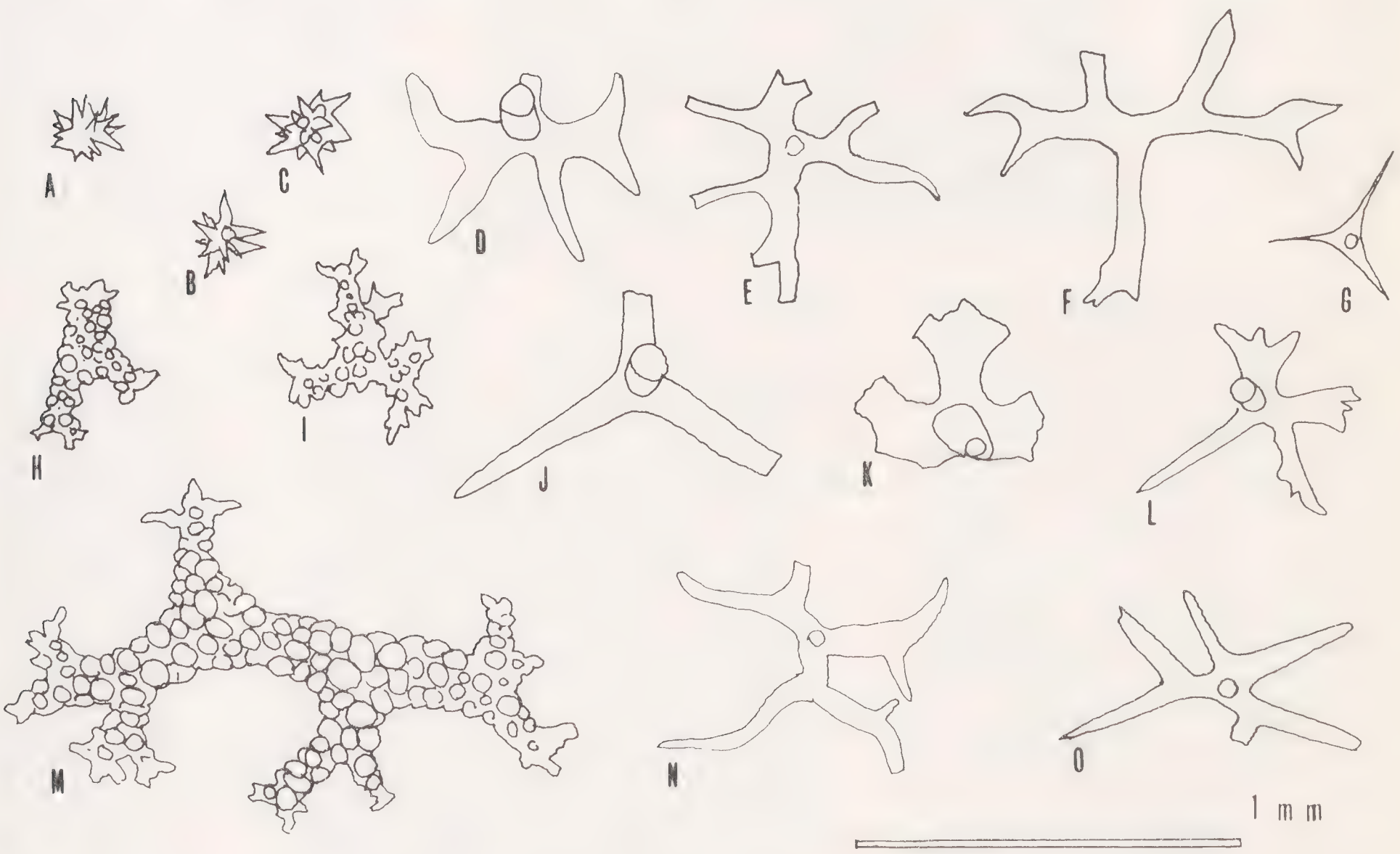
individual spicules become round and more robust. The obvious fine arborescent ray tips of the tetraclones become confused and thoroughly fused to the adjacent, more interior, spicules of the skeletal net. There is a general increase in size of individual nodes on the spicule surface, as well. In the smallest, presumably most recently formed, spicules these individual nodes or irregularities are separated by a short distance of moderately smooth main ray axis surface. Individual irregularities increase in size, however, so that on most robust spicules the hemispherical warts are side by side, or in some instances, actually impinge to produce almost a polygonal packing of the irregularities on the spicule surface.

Individual spicules articulate such that in the outer and dermal parts of the wall there are skeletal openings 0.18 to 0.25 mm across. These rounded openings are produced by gentle arching of individual spicule clads as they articulate with distal surfaces of more interior spicules. The larger canals interrupt the spicule pattern and are cross-connected with the openings between rays in the main body spicules.

The dermal layer is only intermittently preserved apparently because these spicules were not thoroughly fused to the main skeletal mass. As a consequence, the layer is moderately intact only in isolated areas on the crest of ridges between the surficial canals. More often these small spicules are preserved in canals or on flanks of canals. The dermal layer is dominated by dichotriaene-based spicules (Text-fig. 3-D-G, J-L, N, O) that have one long proximal ray and three main rays, the latter tangential to the surface of the sponge. The three primary tangential rays are subdivided on some to produce uniform symmetrical dichotriaenes. In other spicules, which are almost as numerous, one of the primary rays is not subdivided and has a somewhat irregular or wavy trend. This produces a pectactine-appearing spicule, but with the three tangential principal rays diverging at approximately 120 degrees. The secondary rays, generally, have a sweeping, almost fork-like appearance. They diverge initially at 50° to 60° to the primary axis but then commonly swing distally to within a few degrees of the primary axis.

Where the dermal layer is still moderately intact, there seems to be no regular orientation of individual spicules to the branch or to the canals.

Some medium to small-sized smooth, normal, tetraxons appear on the surface of the sponge. These range from small spicules, with rays 0.18 mm long and basal diameters of 0.02 to 0.025, up to moderately large spicules that have rays 0.45 to 0.50 mm long and basal diameters of 0.08 to 0.10 mm. In general, these spicules have straight,



Text-figure 3. Spicules of *Achrochordiella vokesi*, n. sp. A-C. Small polyaxons, possible foreign, from the surface of the holotype. D-F, N, O. Dichotriaenes of the dermal net, with paratangential rays having elliptical to circular cross-sections and with cylindrical fragments of proximal rays. G, J. Simple orthotriaenes showing variation in size. H, I, M. Knobby tetraclones of the main sponge body. Larger spicules are from the interior of the sponge wall. K, L. Examples of rare phyllotriaenes with bladed paratangential rays.

smoothly tapering rays that diverge from one another at approximately 120 degrees, three dimensionally. Some spicules are weakly sculptured with irregular low rounded nodes but most are smooth. In general, they are oriented with one ray proximally and the other three paratangentially. In some of these spicules, the three primary paratangential rays bifurcate to produce smooth, pointed secondary tips, that are one-third to one-half the total ray lengths.

In residues cleaned from the surface of one of the paratypes, a few rare phyllotriaenes (Text-fig. 3-K) were also recovered. The three paratangential rays on these spicules are markedly flattened, almost bladed and subdivided. These phyllotriaenes include small forms with basal ray diameters of 0.06 mm and a length of approximately 0.02 mm. The rays broaden into a flat blade and then subdivide into flattened, stubby, secondary rays 0.05 to 0.06 mm long and 0.05 to 0.08 mm wide. Larger, but still rare phyllotriaenes have ray lengths of 0.25 to 0.30 mm and basal ray widths of 0.10 mm. Their rays flare to 0.18 to 0.20 mm wide, then subdivide into two very broad, plate-like, short secondary rays which are 0.08 to 0.10 mm across. These secondary rays have blunt, almost rectangular to slightly rounded terminations.

Proximal rays of these phyllotriaenes have basal diameters of approximately 0.05 mm and are of undetermined length because they were broken as they were removed from the sponge surface. Phyllotriaenes are exceedingly rare spicules as compared to other elements in the dermal layer. Because of this they could be considered as foreign spicules, associated with the matrix, for normal tetraxons, ophirhabds, fragments of dictyid skeletal nets, fragments of lychnisks, and smooth, normal hexactines also occur as rare spicules adhering to the surface or in associated matrix cleaned from the sponges.

Discussion: Because only a single species of the genus is known, differentiation between generic and specific characters is somewhat problematical. Nonetheless spicule size, size of branches, and details of shape variation of the dominant dichotriaene dermal spicules are considered to be of specific rank. The general form, the general skeleton composed of warty tetraclones, with somewhat wavy dichotriaenes are assumed to be the main elements of generic differentiation, when coupled with the growth form.

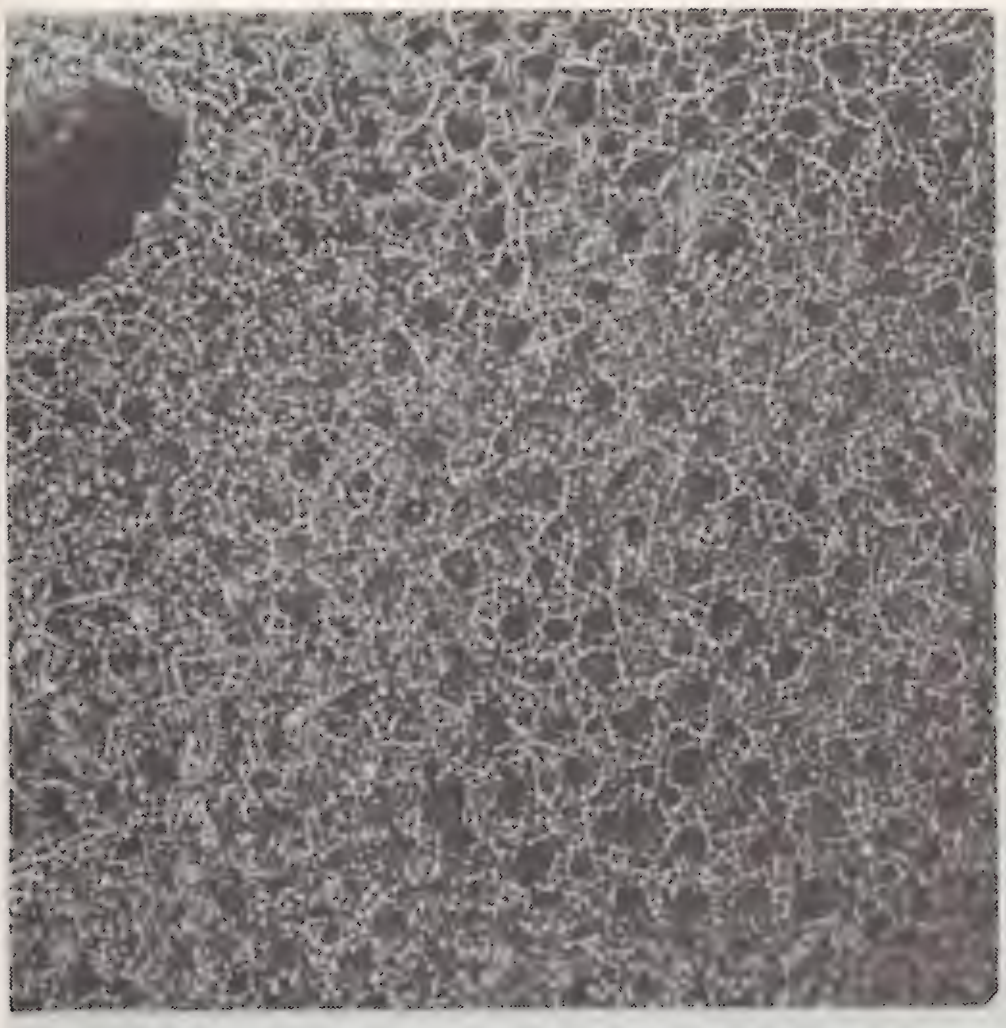
PLATE 2

Ophiraphidites, Haynespongia and Hexactinellid Root Tufts

FIGS. 1, 3, 4, 6 — *Haynespongia vokesae,* n. sp. *1,* Photomicrograph showing dictyonine skeletal net surrounding moderately well-defined large epirhyses. The skeletal net is locally perforated by small circular ostia of apodiarhysal canals. Large opening in the upper left is a lateral osculum to the spongocoel. The skeletal pattern is generalized cribrospongiid, although with considerable irregularity. Holotype USNM 252494. ×10. *3,* Somewhat conical paratype showing the canal pattern of the gastral surface inside the funnel, the dermal surface, and the relatively thin walls characteristic of the species. Bryozoans have encrusted the exterior and produced the regularly spaced openings on the lower left. Paratype, USNM 252495. Natural size. *4,* Photomicrograph of the skeletal net showing expanded nodes at the ray junctions and the net perforated by relatively large epirhyses. Smaller circular openings in the main skeletal net are apodiarhysal canals, which connect to the aporhyses of the gastral margin. Holotype, USNM 252494, ×20. *6,* General view of the subcylindrical finger-like holotype showing prominent lateral osculi to the tubular spongocoel, which extends virtually the entire length of the fragment, and the net perforated by relatively large epirhysal ostia. USNM 252494, Natural size.

FIGS. 2, 5 — Root Tuft. USNM 252493. *2,* Photomicrograph of part of the same specimen shown in figure 5. Characteristic doubly tapering oxeas of varying size make up most of the root fragment. ×20.5, Root tuft fragment showing the distinct parallelism of the dominantly monaxial spicules. Natural size.

FIGS. 7, 8 — *Ophiraphidites hadros,* n. sp. Holotype, USNM 252488. *7,* The relatively massive cavernous sponge is typical of the species, with irregular tracts of the skeletal net surrounded by moderately small canals that interconnect to the large openings throughout the sponge. Broken base shows the densely silicified interior of the specimen. Natural size. *8,* Photomicrograph of the skeletal net showing curved ophirhabds united to form irregular tracts that are separated by variously sized canals. Dense areas are composed, in large part, of fine dichotriaene-based dermal spicules that are much smaller than the principal ophirhabds. ×5.



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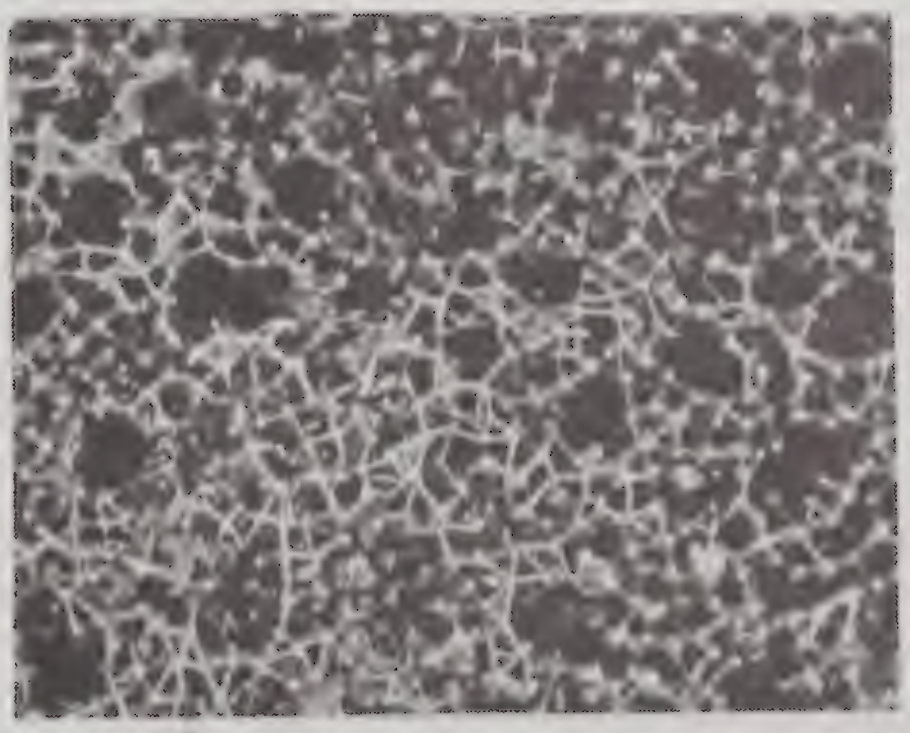

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PLATE 2

Two small fragments of a lychniskid sponge apparently overgrew or attached to a paratype, as did a variety of laminar cheilostome bryozoans, spirorbid worms, and other benthonic forms. Bryozoans apparently encrusted the sponge when it was partially alive, because bryozoan colonies are incorporated within the sponge.

In one of the paratypes there are several arcuate, rounded, depressions in the basal part, as if the sponges had overgrown moderately smooth bivalves, snail fragments, or pebbles. This is the only indication of the method of attachment of these rigid sponges to the substrate.

Type material: Holotype USNM 252489, and paratypes USNM 252490-252491 and BYU 1542 are in the collection. In addition, slides of individual spicules were prepared from residues gathered from each of the sponge surfaces representing, in part, dermal or body spicules and in part, extraneous foreign spicules and debris.

The North Carolina occurrence represents an extension of the family into the Tertiary, from the single described Cretaceous locality of northern Germany. These sponges also represent the first occurrence of the family in North America.

Etymology: The specific name *vokesi* is proposed for Harold Vokes, collector of the fauna and long time student of Tertiary fossils of the Atlantic and Gulf Coastal Plain.

Class HEXACTINELLIDA Schmidt, 1870
Subclass LYSSACINA Zittel, 1877
Order LYSSACINOSA Zittel, 1877
Suborder AUTODERMARIA Reid, 1958
Superfamily EUPLECTELLOIDEA
Gray 1867 (*nomen translatum* Finks, 1960)
Family EUPLECTELLIDAE Gray, 1867

REGADRELLA TRABECULA, n. sp.
Plate 1, figs. 3, 4

Diagnosis: Flabellate to low-conical sponges composed of confused, relatively dense matte of hexactines and hexactine-derived spicules, fused where rays cross and by synapticulae and synapticular webs. Ladder-like beams in skeleton formed of subparallel spicules united with synapticulae. Parietal gaps well defined, cross-connected with smaller radial to diagonal canal series.

Description: A fragment, approximately 50 × 60 mm square, of a broad, cylindrical or conical sponge is in the collection. It was probably part of an example approximately 16 cm in diameter, judging from curvature of specimen. The fragment of the wall is 9 to 10 mm thick but tapers in the upper 20 mm, so it may represent part of the upper wall.

The wall is perforated by large parietal gaps, which extend completely through the net, and by smaller canals, some of which pass through the net whereas others penetrate only part way into the wall, normal to the surface, or angle diagonally within the wall. Several canals expand inward to nearly double their exterior diameter. This is particularly evident in intermediate size canals. Most common exterior canal openings are 0.6 to 0.8 mm in diameter and are nearly circular. Next most common canals are less circular to distinctly elliptical and range from 0.9 to 1.2 mm wide and up to 2.0 mm high. Least common openings are the largest, strongly elliptical parietal gaps, which are 1.4 to 2.5 mm across and up to 3.5 mm high. All of these large gaps go through the wall. Smaller triangular to polygonal skeletal openings are highly irregular because of the matted arrangement of spicules and synapticulae. Interior openings are more circular, although the largest canals are still vertically elongate (1.4 to 0.2 mm wide and up to 3.0 mm high). Those that are approximately 1.0 mm across are mainly circular, although a few range up to 2.0 mm high at the entrance.

The skeletal structure is composed of a confused matte of small hexactines and larger diactines, all fused into a solid structure where spicule rays lie across one another, and by fused, regularly spaced, synapticulae and synapticular nets. Major tracts are composed of fused subparallel spicules, principally vertically oriented, although diagonal and nearly horizontal tracts also occur.

Largest spicules have rays up to 0.34 mm in diameter and at least 5 mm long, but most of the net is composed of spicules that have rays approximately 0.06 to 0.08 mm in diameter and less than 2 mm long. Exact proportions are difficult to determine because of the irregularly fused and synapticulate nature of the net. Spicules with rays as small as 0.01 to 0.02 mm in basal diameter and 0.1 mm long are present, although they are generally lost or obscure in the synapticulate structure.

Synapticulae are generally 0.02 to 0.04 mm in diameter at their thinnest between expansions where they are fused to adjacent spicules. Bar-like synapticulae usually extend for less than 0.2 mm between spicules. Where spicules are more widely spaced, there is a perforate net that unites adjacent spicules.

The overall appearance is of a series of interrunged ladders uniting to develop larger open beams, which are irregularly interleaved and matted. Openings between synapticulae vary from "ladder" to "ladder" but are commonly approximately 0.1 mm in diameter or less. They are smaller when the main spicules are separated by less than that distance. Intersynapticular open-

ings are rounded and vary from circular to strongly elliptical.

Secondary overgrowth of silica may have welded several "ladders" into a solid rod or beam with infilling of synapticular openings. These compound beams may be as large as the largest spicules, up to 0.3 mm in diameter. Overgrowths and the matted nature of the skeleton have obscured the original skeletal elements so that only rarely are ray junctions of hexacts seen, and these are mainly in smallest spicules, which apparently have been coated least. In general, the hexactine origin of the skeletal net is obscure.

Viewed from the side, in the vertical section, most spicules have rays subparallel to the elongate trend of the sponge wall, so that most other rays are oriented at high angles to the sponge exterior or interior. Most compound beams are also oriented parallel to the exterior surface, although they are at various angles to one another in the general plane of the sponge wall.

There is a series of irregular, densely and finely spiculed, subhorizontal bands that may mark former positions of the oscular margin. These show as weak ribs on the exterior and are traceable through the sponge wall. They have an upward arcuate profile, as seen in vertical sections through the wall. These skeletal bands are 2 to 3 mm thick and are present as dense discontinuous layers, which are spaced 5 or 6 mm apart, where most clearly defined in the skeletal net. Compound "beams" are ill-defined in the dense bands but do extend upward and downward within the sponge. These dense layers are composed almost entirely of short rayed spicules and synapticulae, with diameters of 0.02 to 0.03 mm or less. As such, the bands appear less matted and much less irregularly spiculed than most of the remainder of the sponge.

A small patch of fan-like radiating spicules is present on the exterior, near one of the dense layers. It has a radius of approximately 2 mm and appears to be a ropy tuft of spicules with diameters of 0.02 mm and less. it may represent part of a root tuft or it may be unrelated.

Discussion: The North Carolina species is somewhat similar to *Regadrella petrijacob* Schrammen (1912, p. 208; pl. 27, figs. 9-11), but is a larger form and is more densely spiculed. It also has thicker, more closely spaced wall elements, which result in smaller canal and parietal gap openings.

Proeuplectella fragilis Moret (1926, p. 204, pl. 9, fig. 1) is related in terms of a synapticulate and otherwise fused skeletal net but clearly is more open textured than the present specimen and lacks the well defined ladder-like compound beams that are distinctive of the North Carolina species.

Type specimen: Holotype USNM 252492.

Etymology: Trabecula, Latin, little beam, referring to the small compound beams formed by spicules united by synapticulae.

Genus and Species Undetermined
Root Tufts
Plate 2, figs. 2, 5

Two root tuft fragments occur in the collection. The largest is elongate, approximately 45 mm long and 30 mm across, and is composed of a rope-like, somewhat twisted matte of subparallel spicules, which range up to 5 mm long. Most appear to be diactines and are smooth doubly tapering oxeas. Rarely are both tips of the large spicules preserved, however. In the shorter spicules, where both ends are preserved, the tips are sharply pointed. Spicules are mainly approximately 0.15 mm in diameter, at midlength, and taper uniformly in both directions to sharp tips. Oxeas are the most common spicules throughout the tuft body.

Protriaenes and dichotriaenes are also preserved, in a small area, presumably from the outer part of the tuft. They are uniformly oriented. Primary rays in both protriaenes and dichotriaenes and the secondary rays in dichotriaenes are approximately 0.10 mm long. Primary rays are robust, have diameters of 0.08 to 0.10 mm, and taper slightly. Secondary rays have basal diameters of 0.06 to 0.08 and taper sharply to somewhat rounded conical tips.

Primary rays diverge at approximately 120° from center and swing to diverge from 50° to 90° from the trend of the main spicule axis. In some spicules the rays swing again to lie nearly parallel to the axis, but in others they remain nearly at right angles, particularly in the protriaenes.

Spicules of the smaller fragment are all sharply pointed, smooth, oxeas where spicule shape can be determined, but most are broken. Spicules are in a twisted tuft, are curved, and range up to 0.10 mm in diameter, though most are smaller. They are up to 5 mm long and are subparallel to parallel, commonly with mutually adjusted tapering boundaries.

Much of the root tuft is composed of spicules with maximum diameters of 0.04 to 0.05 mm. These small spicules appear to fill in areas between "ropes" of larger spicules within the tuft, or locally they appear to occur at the periphery of the tuft.

Figured specimen: USNM 252493.

Subclass HEXASTEROPHORA
F. E. Schulze, 1887
(emended F. E. Schulze, 1899)
Order HEXACTINOSA Schrammen, 1903
(emended Schrammen, 1912)
Suborder SCOPULARIA
F. E. Schulze, 1885
Family CRIBROSPONGIIDAE
F. A. Romer, 1864

HAYNESPONGIA, n. gen.

Diagnosis: Irregular leaf-like or anastomosing to thin-walled tubular cribrospongids lacking pronounced sculpture. Dictyonal net euretoid with primary framework at gastral margin and strands emerging at high angles on the dermal surface. Primary canals show diplorhysis with general alternation of epirhyses and aporhyses, although not in well defined linear series. Apodiarhysal canals connect to dermal surface and occur in net between epirhysal ostia.

Discussion: The new genus *Haynespongia* appears in general growth forms much like several species of *Eurete,* as for example *Eurete formosum* Reid (1958, p. 21-22, Pl. 2, figs. 7, 8) or *Eurete mantelli* Reid (1958, p. 23-25, Pl. 4, figs. 1, 2). The South Carolina genus differs from *Eurete* in having a cribrospongid rather than a simple canal pattern. *Pachyascus* Schrammen (1936, p. 35-36) appears somewhat similar, as well, but has a craticularid canal pattern.

Polyopesia Schrammen (1902, p. 25-26) was included within the emended Cribrospondiidae by Reid (1964, p. cxlvii), along with others, and differs from the South Carolina genus in being much coarser textured and in having a cylindrical form. Other genera also included in the family by Reid include *Andreaea* Schrammen (1902, p. 25), *Guettardiscyphia* Fromentel (1860, p. 39), *Cribrospongia* d'Orbigny (1849, p. 547), *Walcottella* de Laubenfels (1955, p. E-82), and *Tremadictyon* Zittel (1877, p. 46). These genera all show much more regular conical to cylindrical forms and have much greater regularity in their canal patterns.

Stichmaptyx Schrammen (1912, p. 255), also included in the family by Reid (1964, p. cxlvii), is an irregularly shaped sponge, but has a much more regular canal pattern and canals that penetrate nearly through the walls, much more deeply than in *Haynespongia.*

Stereochlamis Schrammen (1912, p. 231) was also included in the emended family and has an irregular cribrospongid canal pattern reminiscent of *Haynespongia,* but species included in the German genus are small conical forms.

PLATE 3

Achrochordiella, Ophiraphidites, and "Worm Tubes" from Eocene Castle Hayne Limestone from North Carolina

FIGS. 1-3, 5 — *Achrochordiella vokesi,* n. gen., n. sp. *1,* Paratype shows the characteristic broad, indented, surficial canals and the somewhat fused, but arborescent, growth habit of the sponge. Internal canals apparently are bridged former surficial canals. During growth many of the numerous surficial canals were filled with spicules to produce the massive interior of the sponge. Paratype, USNM 252490, Natural size. *2,* Holotype showing the branched arborescent nature of the sponge, with a relatively massive base but with finger-like digitations in the upper part, all marked by anastomosing to vertical surficial grooves. USNM 252489, Natural size. *3,* Tetraclones of the principal skeletal net are sculptured with rounded nodes. Spicules tips are fused to the distal margin of more interior spicules. Arcuate spicules produce the open skeletal net characteristic of the sponge. Holotype, USNM 252489, ×10. *5,* A cluster of dichotriaenes of the dermal net on the holotype, preserved as a low ridge across the principal skeletal net along the flank of one of the exterior canals. Irregular branching of the somewhat elliptically-sectioned rays is characteristic of the species. Holotype, USNM 252489, ×20.

FIG. 4 — "Worm" tube composed of sponge spicules, principally oxeas, although the specimens are attached to a dictyid sponge and *Ophiraphidites.* USNM 252497, ×2.

FIG. 6 — *Ophiraphidites infundibuliformus* Schrammen, 1910. Photomicrograph of a somewhat tubular form, showing the difference in the general skeletal makeup of the irregular exterior versus the somewhat bundled interior. Irregularities of the skeletal net are paralleled by the canal system. USNM 252487, ×2.

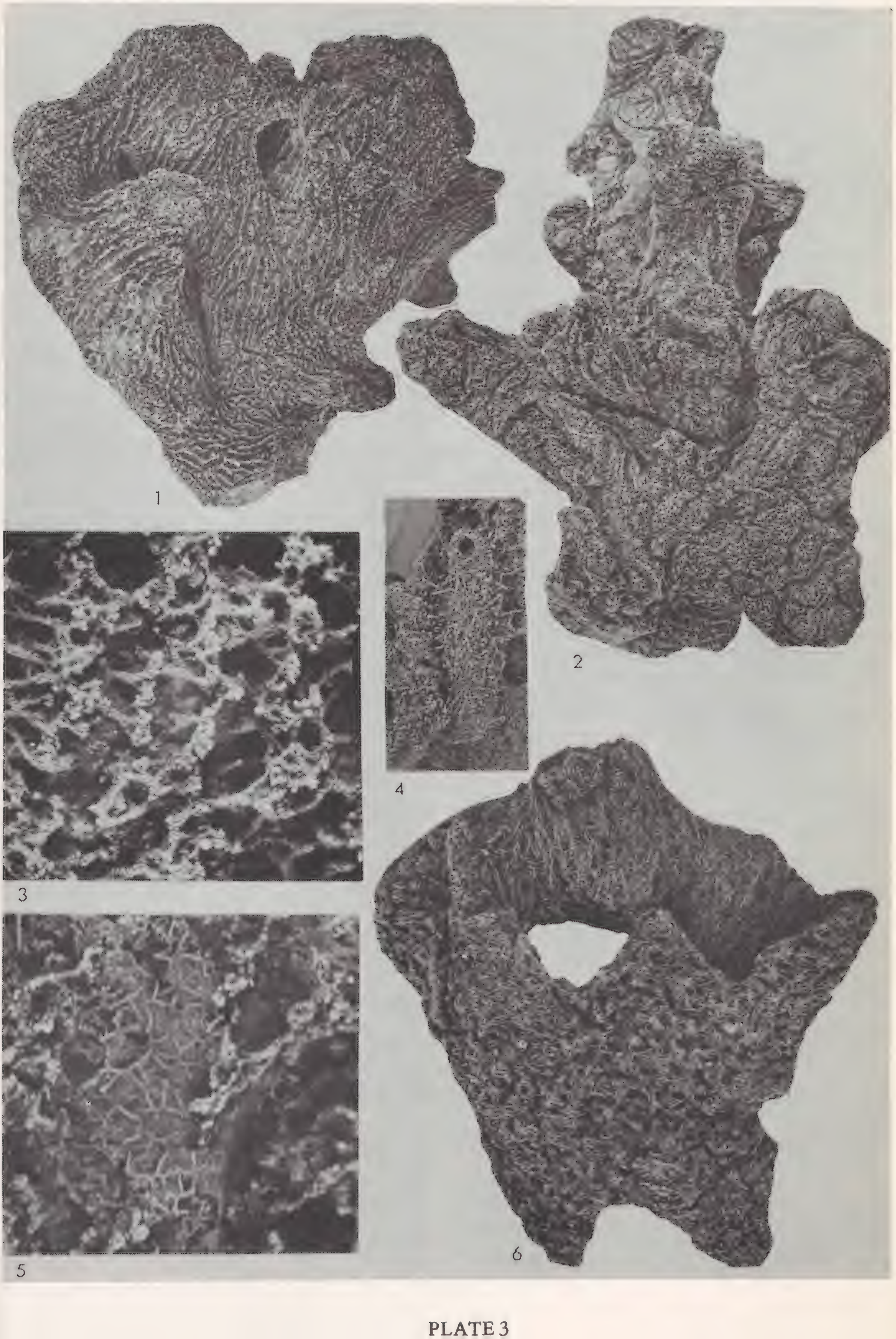

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PLATE 3

Type species: Haynespongia vokesae, n. sp.

HAYNESPONGIA VOKESAE, n. sp.
Plate 2, figs. 1, 3, 4, 6

Diagnosis: Irregular leaf-like or anastomosing sponge from which extend hollow, simple or branching tubes up to 25 mm in diameter with lateral osculae. Surface smooth or with weak mounds or annulations around osculae. Skeletal net euretoid with primary framework at gastral margin, with spicular nodes 0.25 to 0.30 mm apart and strongly swollen in outer part of wall where synapticulae also most common. Primary canals show diplorhysis in cribrospongid arrangement although distinct alignment is ill defined. Aporhysal chambers 0.40 to 0.55 mm in diameter and separated by 0.4 to 0.7 mm of net, connected to exterior by apodiarhysae 0.15 to 0.20 mm in diameter. Latter canals occur between epirhysal chambers that are 0.20 to 0.35 mm in diameter and separated by 0.4 to 0.5 mm of skeletal net.

Description: The sponge, as reconstructed from numerous available fragments, consists of an irregular anastomosing, tubular, leaf-like mass, from which extend numerous cylindrical, simple or branching tubes, commonly the most nearly intact part of the sponge preserved. The tubes apparently arise from the irregular, uneven, leaf-like base at low irregular mounds extending from minor lateral oscular openings. The preserved tube fragments range from 11 to 12 mm in diameter, up to relatively large tubes, 20 to 22 mm in diameter. Many are slightly elliptical with a long axis half again that of a short axis. Some of this undoubtedly is related to modification following burial for many of the tube fragments are perfectly cylindrical.

Exterior of the tubes is relatively smooth, marked here and there with weak, round, irregular annulations arranged approximately normal to the long axis of the tube. Many of the tubes show virtually no modification, other than weak, wavy annulation in their general profile. Except for low mounds that surround the lateral osculae, there is no evidence of major surficial or dermal canals nor significant ribbing. The only modification of the surface is produced by mounds of the lateral osculae. The surface is hispid, however, as a result of the unattached rays at the end of the skeletal strands or of lateral beams, where the strands or beams emerge from the sponge surface at a high angle.

All the tubes are perforated throughout their length by a smooth subcylindrical spongocoel or opening. This opening mirrors the variation in diameter of the exterior for the walls of the tubes have remarkably uniform thickness.

The tube wall thickness ranges from 1.5 to 3.3 mm in the fragments that are available. This is also the general thickness of the leaf- or ear-shaped, somewhat open conical fragments of the basal area as well. Most of the tubes, however, show variation in wall thickness only from approximately 1.5 to 2.0 mm although, locally, walls of individual tubes may be up to 2.5 mm for much of their length. In general, wall thickness decreases sharply around the lateral osculae and towards the terminus of the rounded branch, in those rare instances where tips of the tubes are preserved. As a consequence the spongocoel varies from 6 or 7 mm in diameter up to approximately 9 mm in diameter in the largest branches. In those branch tips where the oscular margin is at the terminus of the branch, the wall thins in a somewhat rounded way, to produce a wall that has a bullet-shaped profile in cross-section.

The lateral osculae generally perforate only one side of the wall of the branches. These circular openings range from 2 mm up to 5 mm across, although most are 3 to 4 mm in diameter. There are some elliptical openings for lateral osculae, with the long axis of the ellipse parallel to the tube axis. These are up to 11 or 12 mm long, but are only 3 to 5 mm wide. Most of the openings however, are perfectly circular. All are situated on low humps or mounds that extend a short distance above the general tubular surface, somewhat like a flaring lip. In other instances they are on merely rounded, subhemispherical, irregularities. In these, the lateral osculae are almost always nearly perfectly circular.

The skeletal net is euretoid with a dictyonal framework of the walls composed of the principal or primary framework, which is situated near the gastral margin, and an upward and outward diverging series of dictyonal strands of the main framework. They sweep from nearly tangential at the gastral surface to meet the dermal surface almost at right angles or at a very high angle, with additional strands being formed near or at the gastral surface sweeping upward and outward in the general direction of growth.

Individual dictyonal strands range from 0.04 to 0.08 mm in diameter, but most are 0.05 to 0.06 mm across at their thinnest dimension in between the expanded nodes at the ray junctions. Beams in the structure that are at high angles to the threads, generally, are somewhat smaller, ranging from 0.01 to 0.06 mm in diameter. Some of the smallest beams may be extraneous secondary elements in the main skeletal net, for many of them seem to cross through the roughly quadrangularly arranged skeletal mesh almost like synapticulae.

Swollen nodes range from inconspicuous minor swellings up to spherical enlargements 0.14 to 0.16 mm in diameter. Most nodes, however, in the main part of the skeletal net are 0.08 to 0.12 mm across. Along any individual dictyonal strand, spicular nodes are spaced 0.25 to 0.30 mm apart, with most approximately 0.25 mm apart. This results in 8 or 9 spicule units in thin walls, and up to 12 to 15 spicule units in thick walls, forming along any one individual dictyonal

strand from where the strand starts to diverge from asymptotic to the gastral surface to the dermal surface.

Most of the mesh openings, as seen in longitudinal sections, are roughly quadrangular, with modified rounded margins related to swelling of the nodes and fusion of the rays in the skeletal nets. In radial sections the openings in the skeletal net are approximately of the same dimensions as seen in the longitudinal section. In the interior and subdermal part of the wall, the dictyonal strands are separated by approximately 0.20 mm, although with some irregularity so that there are many more triangular or trapezoidal type openings, as viewed tangentially, than as viewed in vertical sections in the wall. This is a result of more irregularity in beam orientation as they connect variously placed dictyonal strands. These somewhat irregularly oriented, often extraneous, rays must occur at moderately uniform levels within the strands so that in cross-section the regularity of spacing of the nodes and beams is not interrupted but is varied when seen in tangential view. There is some variation of thickness of beams within the dictyonal strand, as well as of the lateral beams that cross connect the strands.

There is an ill-defined dermal layer, which is characterized by slightly thicker beam development, slight enlargment of the spicule nodes, and a significant increase in the number of small adventitious rays or synapticulae. The regular skeletal strands extend into and through the dermal layer, with the sharp pinnacled to steeply conical, unattached, rays extending through the dermal layer. Extraneous small skeletal elements in the dermal layer are generally less than 0.01 mm in diameter but may be long enough to extend from node to beam. They make the dermal surface of the sponge considerably more dense than the regular skeletal net of the interior.

Primary canals show fully developed diplorhysis, with well defined epirhyses and aporhyses. These radial canals are in characteristic cribrospongiid arrangement, in that within any linear series there is an alternation of epirhysid and aporhysid chambers. The distinct linear arrangement characteristic of many genera included within the family is ill-defined or wanting. In general, however, a single aporhyses is surrounded with quincuncially arranged epirhyses, so that the cribrospongid pattern is moderately well-defined.

The aporhyses, in addition to being open at the gastral margin, are connected with small canals to openings 0.15 to 0.20 mm in diameter on the dermal surface, and should be designated as apodiarhyses where that situation exists (Reid 1964, p. civ). Epidiorhyses are apparently not well developed, if present at all.

The epirhyses chambers are almost subcylindrical on the outer part of the wall, but have a rounded base where they are lost in the finer textured dictyonal net, in the middle to gastral half of the wall. In general, the epirhysal chambers are well-defined and uniformly scattered over the entire exterior of the sponge. They range from 0.20 to 0.35 mm in diameter with most 0.25 to 0.30 mm across. They are separated by 0.4 to 0.5 mm. They are not obviously stacked in horizontal nor vertical series, but are uniformly spaced and are so arranged that six to eight individual canals lie along a vertical line 5 mm long. They also have similar horizontal spacing.

Smaller ostia of the apodiarhysal canals are distinctly smaller than the main canals, are uniformly circular, and are placed in the central part of the space between the ostia of the epirhysal systems. These small tubular canals connect to the expanded aporhysal chamber that indent the gastral margin of the wall. They mark the tips of the rounded to V-shaped bases of the aporhysal chambers and, as such, enable clear definition of the cribrospongiid canal pattern.

Postica of the aporhysal systems are considerably larger. Most range from 0.40 to 0.55 mm in diameter. They are circular and the aporhysal chambers extend one third, or slightly less, of the wall-thickness into the sponge wall from the gastral margin, where they abruptly narrow and terminate, or continue through to the dermal surface as apodiarhysal canals. There are five or six aporhysal chambers in 5 mm, measured vertically, and six to eight in 5 mm, measured horizontally, along the gastral surface. In general, in any vertical series aporhysal chambers are separated by 0.4 to 0.7 mm of skeletal material but may be separated by considerably less horizontally, with some only 0.25 mm apart. They, like the epirhysal systems, do not fall into any clear vertical, horizontal, or diagonally ascending series of geometric patterns, but show considerable irregularity. Aporhysal chambers have sloping, rounded, upper lateral margins rather than the clear, sharply defined limits seen in the epirhysal systems.

In a few fragments that show the basal part of a sponge, the aporhysal chambers converge into large pits that may be 3 or 4 mm across and as much as 1 or 2 mm deep. The marked, irregular, large openings seem characteristic only of the lower part of the sponge in the zone of attachment, however, and are not characteristic of the gastral surface of the upper tubular or leaf-like parts of the sponge.

Surfaces of the beams and strands may be locally ornamented with small granules. Some of the sculpture may be a result of adhering foreign material, during silicification and fossilization, or may be related to original construction.

Discussion: Reid (1958-64, p. cxlv-cliv) proposed a new classification of the Order Hexactinosa, including two suborders, the Clavularia (F. E. Schulze, 1885) and the Scopularia (F. E. Schulze, 1885), based

upon the occurrence of unique associations of microscleres in living forms. He has extended this classification to include fossils and included most of the dictyid hexactinellids in the Scopularia. He has arranged genera of Hexactinosa into eight families that are differentiated, in large part, upon the basis of the manner of formation of the skeletal net, as well as upon characteristics of canal development in the skeletal net. In the process he grouped together many of the numeroius families described by Schrammen (1912, 1924, 1926). Reid (1957; 1958-64, p. clic-liv) is highly critical of the classification of the hexactinosid sponges proposed by DeLaubenfels (1955, p. E78-E92), which was based, in large part, on habit and external appearance.

North Carolina specimens differ from those listed by Reid (1964, p. cxlvii) as examples of genera included in the Family Cribrospongiidae, in being consistantly finer textured, more consistantly tubular, and in having a less linearly arranged canal system, although the general cribrospongiid pattern, as defined by Reid (1958-64), is present. These dictyid sponges are a common base for attachment of encrusting unilaminar cheilostome bryozoans, as well as other sponges in the assemblage, particularly *Ophirhaphidites infundibuliformis*.

Type material: Holotype USNM 252494 and paratypes USNM 252495 and 252496. In addition, reference specimens are deposited in the Department of Geology, Brigham Young University (BYU 1543 and 1544). In total, approximately 80 moderately complete tubes or fragments of the sponge are in the collections from the Castle Hayne Limestone of North Carolina.

Etymology: The species is named for Emily Vokes, one of the collectors of the sponge fauna and a student of coastal plain geology.

Order LYCHNISCOSA Schrammen, 1902
Family UNCERTAIN
Genus UNCERTAIN

Description: Two small encrusting fragments occur in the collection. Both are attached to the same sponge and possibly were continuous at one time. The larger fragment is approximately 2.5 mm wide and 9 mm long, the smaller one is approximately 2 mm by 3 mm. Both are approximately 1 mm thick and show the same general development of canals and a skeletal net lacking a dermal layer.

Largest, presumably excurrent, canal openings, are 0.5 to 0.75 mm across. They are roughly round, but some are polygonal, defined by moderately straight segments of the skeletal net. Canals are spaced from one skeletal element up to 0.6 mm apart.

The intermediate-sized canals are 0.25 to 0.40 mm across and are similarly subpolygonal to subcircular. These may represent two distinct sizes because several are approximately 0.25 mm across. Smaller openings within the main skeletal net, between adjoining spicule rays, are 0.05 to 0.10 mm across. These are triangular to polygonal or subcircular, and occur in the middle of skeletal webs.

Individual beams of the spicules are 0.25 to 0.40 mm long and 0.025 to 0.040 mm across, except where they bifurcate to articulate with adjacent spicules in the web-like arrangement. At the articulation there is a slight nodal development, which is up to 0.06 mm across where most clearly defined. Subsidiary rays in the lattern-like lychnisks are small elements, 0.06 to 0.10 mm long and from 0.01 mm up to 0.025 mm across. The most delicate parts of the net are the tiny ray junctions in the centers of lychnisks.

The skeletal net resembles a demosponge lithistid in its growth pattern with the lack of a noncubic arrangement and the ray tips that seem to articulate with tips of other rays except for the development of lychnisks. There is a distinct linearity to the skeleton, however, with individual canal series 0.50 to 0.75 mm apart.

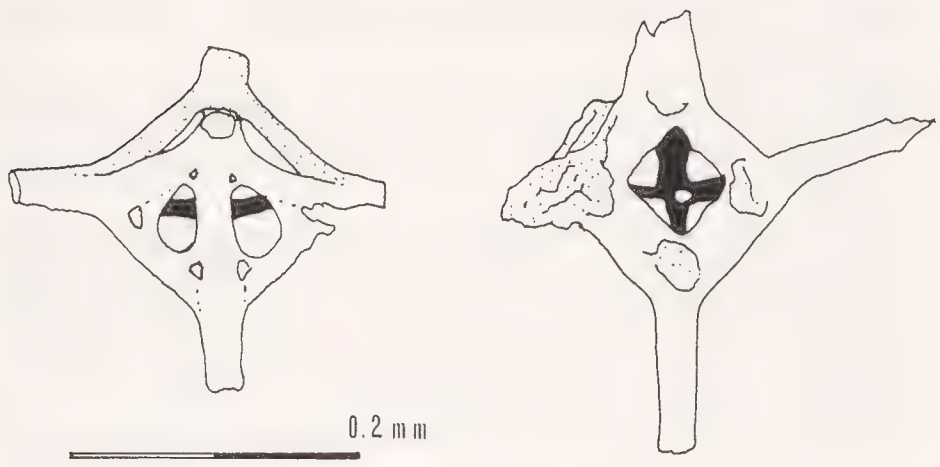
Discussion: In general, spicule shape and size of the form resemble *Trembolites* Zittel (1877, p. 55-56), but the sponge has a more compound beam-like pattern, somewhat like that of *Coscinopora* Goldfuss, (1826, p. 30). Both of the above genera are from the Cretaceous of Europe. However, most of the Lychniscosa described, so far, have been moderately large sponges and an encrusting or attached form has not been defined. As a consequence, generic placement of these fragments is uncertain. This is the first lychniscosid sponge recorded from North America. It is unfortunate that the material is so fragmental and inconclusive.

Isolated Lychnisks
Text-fig. 4

Isolated lychnisks were recovered in acid residues from one of the paratypes of *Achrochordiella*. The small lantern-shaped lychnisks are 0.15 to 0.16 mm across in each of the three fragments. From this, lantern rays extend approximately 0.15 mm and have a diameter of 0.04 mm at the bifurcation where the cross-bracing buttresses

diverge from the main ray. These cross-bracing buttresses are 0.08 to 0.10 mm long and 0.02 to 0.03 mm wide, in the central narrow part, and make triangular openings 0.06 mm across from the ray junction. These isolated lychnisks are considerably larger than equivalent units in the small sponge fragments. They clearly show, however, that the Order Lychniscosa is present in the North American Tertiary.

Figured specimens: BYU 1546 and 1547.



Text-figure 4. Isolated lychnisks from matrix associated with *Achrochordiella vokesi*, n. sp., Eocene Castle Hayne Limestone. BYU 1546, 1547.

Phylum Uncertain
"Worm Tubes"
Plate 3, fig. 4

Two small subcylindrical to pupaeform spicule-lined "worm tubes" occur in the collection. The larger is 17 mm long, 4 mm wide, and 2 mm thick and the smaller is broken but is now 8 mm long, 3 mm wide, and 1.5 mm thick. The smaller specimen was at least 13 mm long, judging from broken fragments cemented to the substrate.

Both tubes are long and sack-shaped, with smooth circular openings emptying through a circular aperture, which is 1.5 mm in diameter. The broken smaller specimen has an elliptically cross-sectioned tube, possibly because of flattening during fossilization, which is 2 mm wide and 0.8 mm high. In the large specimen the tubular central opening is sharply flexed, to open parallel to the wall, rather than terminally and normal to the wall trend.

The wall is composed of matted spicules, almost exclusively oxeas, even though the specimens are attached to *Ophiraphidites* and a dictyid sponge. The spicules range from small ones, 0.02 mm in diameter and approximately 0.5 mm long, up to those 0.20 mm in diameter and 4.0 mm long. The large spicules are inserted into the wall at various angles. A few triaenes, like those which occur as dermal elements in *Ophiraphidites*, occur on the fine textured upper wall.

Figured specimen: USNM 252497.

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PLANKTIC FORAMINIFERA AND CALCAREOUS NANNOPLANKTON BIOSTRATIGRAPHY OF THE NEOGENE OF MEXICO

ADDENDUM TO PART I — SOME ADDITIONAL MID-PLIOCENE LOCALITIES AND FURTHER DISCUSSION ON THE AGUEGUEXQUITE AND CONCEPCION SUPERIOR BEDS.

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The youngest exposed beds in Mexico of bathyal and outer neritic origin are the Agueguexquite, Filisola, Concepcion Superior, and Concepcion Inferior "Formations." Pioneer geologists referred these outcropping strata to various parts of the geological column, but planktic guide fossils now provide a precise basis for the assignment of these beds to Neogene Zone 20, approximately middle Pliocene, as recognized in the Initial Reports of the Deep Sea Drilling Program.

The above strata, in addition to older Neogene beds to be discussed in later parts of this series, comprise the Coatzacoalcos Formation, as erected by Spencer (1897, p. 23-25) for the marine clays that in some places rest upon decomposed gneisses and are exposed in highway, railway, pipeline, and stream cuts in the Isthmus of Tehuantepec. Later names, including Agueguexquite, Filisola, Concepcion Superior, and Concepcion Inferior, have been applied to paleontologic subdivisions of the Coatzacoalcos Formation (based on benthic foraminifera), and they are, therefore, invalid in a strict sense as names of formations.

Most of the planktic foraminifera and calcareous nannofossils that occur in the middle Pliocene of Mexico are not restricted to this portion of the geological column but have their evolutionary first occurrences in older sediments and continued to live into later Pliocene or Quaternary times. Some of the planktic microfossils, however, had either their incipience or their extinction during the middle Pliocene, and the concurrence of these forms in beds within middle and low latitudes indicates a stratigraphic position within Zone N. 20 (middle Pliocene). The following forms have been found particularly useful, as follows, for the recognition of Zone N. 20 in Mexico (fig. 1): The latest occurrence of the planktic foraminifera *Globorotalia (G.) margaritae* Bolli and Bermúdez and *Sphaeroidinellopsis subdehiscens subdehiscens* (Blow) is in Zone N. 20; the calcareous nannoplankton *Sphenolithus abies* Deflandre and *Reticulofenestra pseudoumbilica* (Gartner) are last seen in Zone N. 20; the incipience of two species of calcareous nannofossils, *Gephyrocapsa caribbeanica* Boudreaux and Hay and *Pleudoemiliania lacunosa* (Kamptner), occurred within Zone N. 20, and these forms became more abundant during the upper Pliocene and Quaternary.

Three additional sites have been visited and sampled subsequently to my report on the middle Pliocene, and they should be added to the localities already described under this heading (Akers, 1979). Two of the exposures (TU 1317 and TU 1318) are in the vicinity of TU 1025, which is the Concepcion Inferior of Contreras Velazques *et al.* (1956, p. 176), and were made accessible by new pipeline construction. The lithology at both additional localities is a medium gray clay with black, carbonaceous plant inclusions. Residues on a U. S. Standard Sieve Series, no. 200, are predominantly carbonaceous plant material with some small mollusks. See below for the lithology at TU 1321.

LOCALITY TU 1317

Pipeline cut on hill just west of Nueva Teapa on north side of Mexico Highway 180, state of Veracruz, Mexico. Collected, 1979, by H. E. and E. H. Vokes. The following planktic foraminifera were identified:

Biorbulina bilobata (d'Orbigny)
Globigerina decoraperta Takayanagi and Saito
Globigerinita glutinata (Egger)
Globigerinoides conglobatus conglobatus (Brady)
G. obliquus extremus Bolli and Bermúdez
G. quadrilobatus quadrilobatus (d'Orbigny)
Globoquadrina altispira altispira Bolli
Globorotalia (G.) cultrata menardii (Parker, Jones and Brady)
G. (G.) margaritae Bolli and Bermúdez
G. (Turborotalia) acostaensis acostaensis Blow

G. (T.) acostaensis humerosa Takayanagi and Saito
Hastigerina (H.) siphonifera siphonifera (d'Orbigny)
Orbulina universa d'Orbigny
Prosphaeroidinella parkerae Ujiie
Sphaeroidinellopsis subdehiscens subdehiscens (Blow)

A partial list of the calcareous nannofossils includes the following:

Discoaster brouweri Tan
D. pentaradiatus Tan
D. surculus Martini and Bramlette
Pseudoemiliania lacunosa (Kamptner)
Sphenolithus abies Deflandre

LOCALITY TU 1318

Hill cut on pipeline northeast of Campo El Chapo, 4 kilometers south of Mexico Highway 180, at Nueva Teapa, state of Veracruz, Mexico. Collected, 1979, by H. E. and E. H. Vokes. The residue of this sample on a no. 200 sieve contains much chlorite and some echinoid fragments, in addition to carbonaceous material and mollusk fragments. The following planktic foraminifera were identified:

Globigerina decoraperta Takayanagi and Saito
Globigerinoides obliquus extremus Bolli and Bermúdez
G. obliquus obliquus Bolli
G. quadrilobatus quadrilobatus (d'Orbigny)
Globoquadrina altispira altispira Bolli
Globorotalia (G.) cultrata menardii (Parker, Jones and Brady)
G. (G.) margaritae Bolli and Bermúdez
G. (Turborotalia) acostaensis acostaensis (Blow)
G. (T.) acostaensis humerosa Takayanagi and Saito
Hastigerina (H.) siphonifera siphonifera (d'Orbigny)
Orbulina universa d'Orbigny

The following calcareous nannofossils were identified:

Discoaster pentaradiatus Tan
D. surculus Martini and Bramlette
Gephyrocapsa caribbeanica Boudreaux and Hay
Helicopontosphaera sellii Bukry and Bramlette
Pseudoemiliania lacunosa (Kamptner)
Reticulofenestra pseudoumbilica (Gartner)
Sphenolithus abies Deflandre

LOCALITY TU 1321

Kilometer 70 on the Trans-Isthmus railroad, south of Coatzacoalcos. The site is a railroad cut, both sides of the tracks, five kilometers north of Almagres, state of Veracruz, Mexico. Collected in 1979 by E. H. Vokes and W. H. Akers. The weathered lithology is a light buff clay. This locality was first collected (for mollusks) in 1895 by J. W. Spencer (1897, p. 14, 24), who cited it as "Kilometer 70." Dall (1898, p. 652-653) referred to Spencer's collection, estimating that the beds "were deposited in deep water, probably between one hundred and fifty and four hundred fathoms in depth, judging by analogous recent species." The locality was again visited in 1904, but the clay was so weathered that hardly a shell fragment could be found (Böse, 1910, p. 215). Dall (1898) and Toula (1910, 1911) described elements of the molluscan fauna collected earlier by Spencer. When the locality was visited in 1979 by the writer and E. H. Vokes, foraminifera and calcareous nannofossils were found in abundance, but no trace of the molluscan assemblage was seen. The following planktic foraminifera were identified at TU 1321:

Biorbulina bilobata (d'Orbigny)
Candeina nitida d'Orbigny
Globigerina bulloides bulloides d'Orbigny
Globigerinita glutinata (Egger)
Globigerinoides conglobatus conglobatus (Brady)
G. obliquus extremus Bolli and Bermúdez
G. obliquus obliquus Bolli
G. quadrilobatus quadrilobatus (d'Orbigny)
G. quadrilobatus sacculifer (Brady)
Globoquadrina altispira altispira Bolli
Globorotalia (G.) cultrata menardii (Parker, Jones and Brady)
G. (G.) margaritae Bolli and Bermúdez
G. (G.) miocenica Palmer
G. (G.) multicamerata Cushman and Jarvis
G. (Turborotalia) acostaensis humerosa Takayanagi and Saito
Hastigerina (H.) siphonifera siphonifera (d'Orbigny)
Orbulina universa d'Orbigny
Pulleniatina obliquiloculata (Parker and Jones)
Sphaeroidinellopsis subdehiscens subdehiscens (Blow)

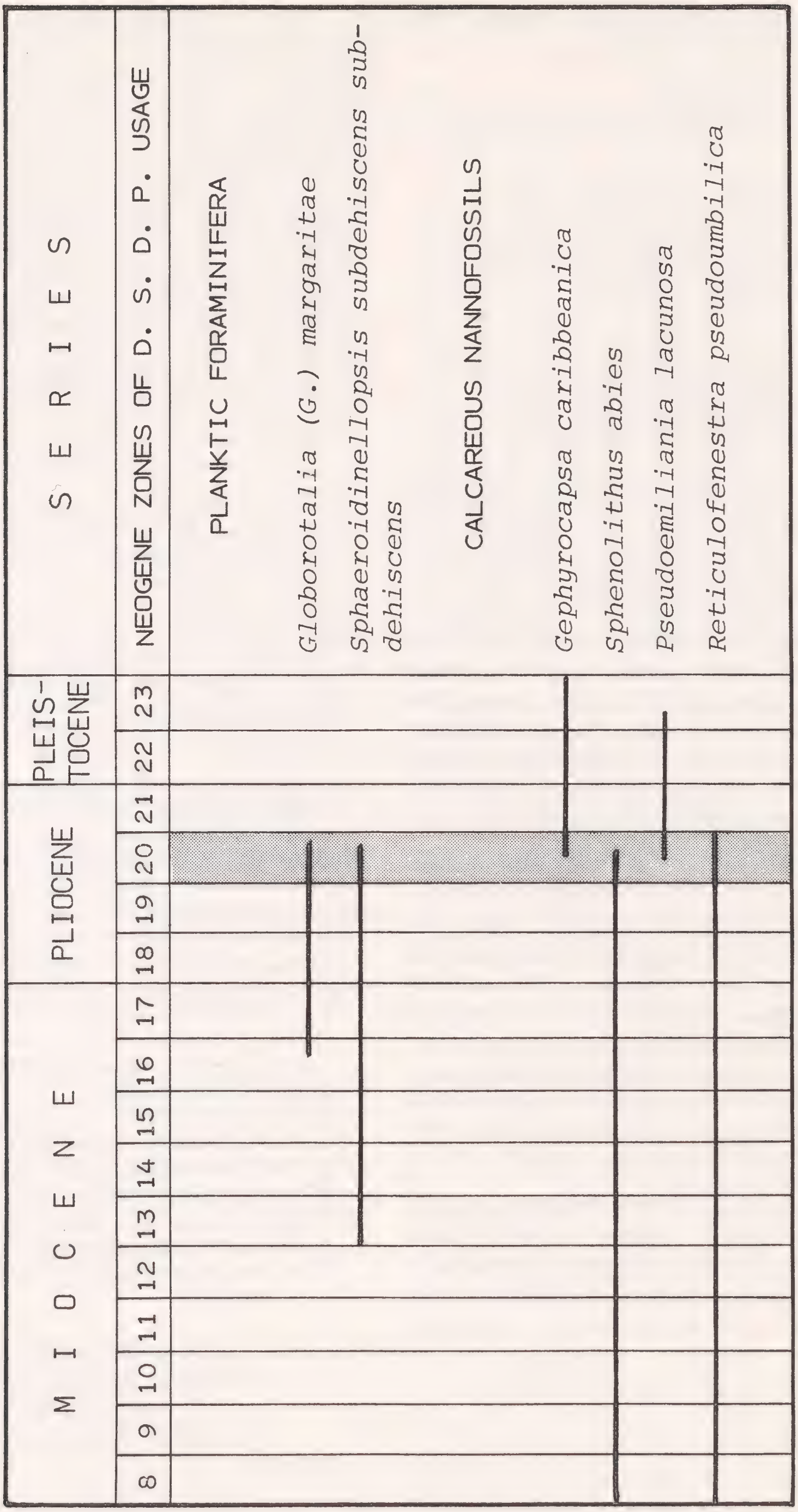

Fig. 1. Ranges of some planktic index fossils in the Neogene of Mexico. The concurrence of combinations of these forms indicates middle Pliocene as recognized in this series of reports.

The following calcareous nannofossils were identified at TU 1321:

Discoaster brouweri Tan
D. pentaradiatus Tan
Gephyrocapsa caribbeanica Boudreaux and Hay
Helicopontosphaera sellii Bukry and Bramlette
Pseudoemiliania lacunosa (Kamptner)
Reticulofenestra pseudoumbilica (Gartner)
Sphenolithus abies Deflandre

FURTHER DISCUSSION ON THE AGUEGUEXQUITE AND CONCEPCION BEDS

Additional study of material from the Agueguexquite beds at TU 638, described in Part I of this series, has disclosed rare specimens of *Gephyrocapsa caribbeanica* and *Reticulofenestra pseudoumbilica,* further substantiating a middle Pliocene, Zone N. 20, position for these strata. To date, *Sphenolithus abies* has not been identified here, suggesting that these beds were deposited just subsequent to the extinction of that species near the middle of Zone N. 20 but prior to the extinction of *Reticulofenestra pseudoumbilica,* which may have occurred higher in Zone N. 20.

Further review of data and examination of additional material from TU 1025 (Concepcion Inferior beds) and TU 1026 (Concepcion Superior beds) has confirmed the existence at both localities of *Pseudoemiliania lacunosa,* precluding a stratigraphic position below Zone N. 20. The frequency of *P. lacunosa* is even higher at the Concepcion Inferior locality than in the Concepcion Superior beds, probably due to more favorable bathymetry than that for the shoaler Concepcion Superior.

The occurrence at TU 1026 (Concepcion Superior) of *Globigerina nepenthes* was reported in Part I (Akers, 1979, p. 7-8) without comment. It should be noted that this species is anomalous in either the Concepcion Superior or the Concepcion Inferior beds, and its occurrence above Zone N. 19 can be attributed only to contamination or mixing of some sort, such as reworking from the older Encanto strata. The occasional occurrence of this "deep-water" planktic species with the neritic benthic assemblage at TU 1026 is also anomalous, moreover, from a paleoecologic point of view. This conclusion is supported by detailed studies on Pliocene and upper Miocene foraminiferal assemblages in the Isthmus of Tehuantepec (Barry Kohl, unpublished doctoral dissertation, Tulane University).

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A REMARKABLE MELONGENID GASTROPOD FROM THE GATUN FORMATION, PANAMA

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The Gatun Formation of the Republic of Panamá and the former Canal Zone — Neogene marine sediments cropping out from Gatun Lake to the Caribbean coast — has been a prolific source of molluscan fossils and the object of intensive study for many years (Olsson, 1942; Keen and Thompson, 1946; Woodring, 1957-1973). One of the more enigmatic mollusks discovered there is the oddly adorned gastropod fragment cited by Woodring (1973, pp. 461, 480, pl. 73, figs. 12, 13) as "xancid? genus?." That author described this puzzling fossil at some length, but its systematic allocation eluded him, and he concluded, "were it not for the columella, it would not be unreasonable to interpret it as a bizarre *Vasum*. It is by no means certain, however, that it is a xancid; it may possibly be a cymatid" (Woodring, 1973, p. 480).

A recent collecting venture by Mr. and Mrs. William D. Pitt of Sacramento, California, turned up, in addition to many other interesting mollusks, a nearly intact specimen of the same species. This specimen provides a basis for a fuller, formal description of the species and an assessment of its affinities. In addition, a new generic name is proposed.

Thanks are due to Drs. Wendell P. Woodring, Harold and Emily Vokes, and Peter U. Rodda for advice and consultation in the course of this study. Emily Vokes's thoughtful critique of the relationships of the new genus was especially helpful. Wayne S. Barnett kindly photographed the holotype under ultraviolet light.

Class GASTROPODA
Order NEOGASTROPODA
Superfamily BUCCINACEA
Family MELONGENIDAE

Genus TORQUIFER Roth, n. gen.

Type-species: *Torquifer pittorum* Roth, n. sp.

Diagnosis: Shell of moderate size for the family, solid, short-pyriform. Whorls coronate, with thick, upturned spines at the shoulder. Parietal callus extensive posterior to aperture, exposed at suture on later whorls. Region between shoulder and suture ornamented with prominent spiral sculpture consisting of raised cords and series of large knobs or beads. Body whorl short, constricted anteriorly. Siphonal fasciole broad, prominent, umbilicate, bordered by a keel.

Discussion: The salient feature of this monotypic genus is the presence of complex spiral sculpture on the area between the suture and the shoulder of the whorl, in combination with a stout body whorl that is most strongly constricted anteriorly. Mature specimens belonging to the related melongenid genera *Melongena* Schumacher, 1817 (type-species *M. fasciata* Schumacher, 1817 [=*Murex melongena* Linnaeus, 1758]), *Volema* Röding, 1798 (type-species *V. paradisiaca* Röding, 1798), and *Pugilina* Schumacher, 1817 (type-species *P. fasciata* Schumacher, 1817 [=*Murex morio* Linnaeus, 1758]), sometimes show subdued spiral sculpture between suture and shoulder, usually consisting of smooth cords more or less interrupted by axial lines of growth. A puckered sutural band occurs in some species of *Melongena* — for example, the familiar *Melongena corona* (Gmelin, 1791) — but consists of raised axial lamellae that are former margins of the anal canal. Similar lamellae border the suture of the Indo-Pacific *Volema myristica* Röding, 1798, and project above the suture as a row of small, hollow spines open toward the aperture. In *Melongena lainei* (Basterot, 1825), Aquitanian of France, the spiral cords between the suture and shoulder are sometimes produced into knobs, concave in the direction of growth; but these are never as complex or prominent as those of *Torquifer*, and the body whorl is subconic with its chief region of constriction being medial, behind the anterior row of spines.

The early whorls of all these forms are similar and have 9-13 blunt axial ribs, usually showing no carination until about the third neanic whorl, crossed by smooth, narrow spiral cords. These cords extend below the shoulder onto the main portion of the whorl. In most species of Melongenidae they tend to become weaker with advancing growth. Their prominence on the adult conch is variable within species and within populations, but they are typically simple and proportionally weaker than on young shells. By contrast, in *Torquifer* three of the early subsutural spiral cords are exaggerated ("transformed," in the words of Woodring, 1973) into rows of knobs as the shell enlarges; other of the cords increase in strength. This diagnostic sculpture is most elaborate at the latest stage of growth.

The short, broad proportions of the shell are similar to some species of *Melongena* and *Volema*, but in many other respects *Torquifer* resembles the predominantly Eocene genus *Cornulina* Conrad, 1853 (type-species ?*Melongena armigerus* Conrad, 1833). A heavy and well defined parietal callus is characteristic of many species of *Cornulina*. The callus of adult *C. armigera* (Conrad, 1833) and *C. minax* (Solander, 1766) is practically as extensive as that of *Torquifer*. *Cornulina* species typically have two spiral rows of spines, the anterior row weaker and sometimes evanescent. The spines are thick and begin as open, triangular scales that seal over with growth, as in *Torquifer*. The region of constriction of the body whorl is in front of the anterior row of spines; as in *Torquifer*, the constricted region bears strongly incised spiral sculpture. The siphonal fasciole is prominent, usually bordered by a keel, and at times umbilicate. A relatively strong anal notch is present. and this sometimes leaves projecting traces below the suture (Plate 1, figure 5).

The Latin name *Torquifer* — one who wears a *torques*, or necklace — refers to the singular adornment on the spire. Its gender is masculine.

TORQUIFER PITTORUM Roth, n. sp.
Plate 1, figures 1-4, 6

Xancid?, genus? Woodring, 1973, U. S. Geol. Surv. Prof. Paper 306-E, 461, 480 (as "Family Xancidae? Genus?"), pl. 73, figs. 12, 13.

Diagnosis: As for genus.

Description: Shell of moderate size for the family, solid, fairly heavy, short-pyriform. Apex not preserved; five remaining whorls. Spire of moderate height, slightly concave in profile, apical angle 75°. First three preserved whorls obtusely shouldered, with nine blunt axial ribs and about five smooth, faint spiral cords between suture and shoulder; later whorls coronate. Suture distinct, impressed, undulating between axial ribs. From about fourth whorl on, band of parietal callus visible at suture, obliquely striated by lines of growth, tumid. Axial ribs of spire transformed, on succeeding whorls, into well-spaced, stout, upturning, triangular spines at shoulder (10 on last whorl). Beginning on third whorl, inner (most posterior) spiral cord enlarging; bordered in front by narrow, flat-bottomed sulcus; becoming nodose, with nodes increasing in prominence and developing medial groove, finally developing into row of closely set, bilobed knobs or beads. Other cords on spire also increasing in prominence, although irregularly, the middle one bearing a series of narrow, compressed knobs, somewhat hook-shaped in direction of aperture; next outboard cord with minor thickenings in rhythm with knobs of middle cord. Body whorl almost smooth in front of shoulder, convex, with sculpture of irregular, fine, spiral lirations and even finer lines of growth; constricted anterior to middle. Lirations more prominent and widely spaced on constricted portion.

PLATE 1

Figures

1-4, 6. *Torquifer pittorum* Roth, n. sp. Holotype, CASGTC 60375. Locality CAS 58335, Gatun Formation, Republic of Panama; middle Miocene(?). 1, 2, 4. Top, back, and front views (× 1). 3. Color pattern as revealed by ultraviolet light (× 1). Photograph by W. S. Barnett. 6. Detail of spire ornamentation (× 1.25).

5. *Cornulina minax compressa* Dockery, 1980 (× 1.6). Figured specimen, CAS 60564; length 49.1 mm, diameter 37.7 mm. Locality TU 656, Bashi Formation, road cut on east side of Alabama Highway 69, south bluff of Bashi Creek, about 1.3 mi north of junction at Campbell, Alabama; lower Eocene.

PLATE 1

Just posterior to constriction, a weak spiral row of small, blunt, widely spaced, triangular spines (four visible on holotype). Siphonal fasciole strong, broad, umbilicate, set off from remainder of whorl by a keel. Parietal callus broad, thick, extending well onto face of body whorl and somewhat posterior to suture; posterior portion detached from whorl between spines of the shoulder; weakly and irregularly spirally grooved, particularly near anterior end. Aperture subovate, smooth within; anal canal small, located under knobs of subsutural spiral cord. Outer lip broken but apparently not thickened; simple or with small marginal denticulations. Anterior siphonal canal short, oblique, twisted backward and to the right.

Length 82.8 mm; diameter 63.6 mm.

Holotype: California Academy of Sciences Geology Type Collection 60375.

Type locality: CAS 58335, north of Transisthmian Highway, about 1 km northwest of Sabanita, Republic of Panama (9°21.25′ N, 79°48.75′ W). Mr. and Mrs. William D. Pitt, January 1977.

Occurrence: Lower part of Gatun Formation, Republic of Panama; middle Miocene(?).

Figured specimen: CASGTC 60375 (holotype). Other occurrence: Locality 138c of Woodring (1964, 1973) (=USGS Cenozoic loc. 21956, about 100 m north of Transisthmian Highway and about 75 m west of road to refinery site on Payardi Island, Panama; R. H. Stewart and Anselmo Mena, 1957); one incomplete specimen (Woodring, 1973, pl. 73, figs. 12, 13).

Discussion: Like certain other mollusks from the Gatun Formation (Pitt and Barnett, 1979), the holotype of *Torquifer pittorum* shows a color pattern under ultraviolet light. The holotype was photographed by the method of Pitt and Barnett (1979), without soaking in sodium hypochlorite. A band is visible (Plate 1, figure 3) near the middle of the body whorl and another, less distinct, just anterior to the shoulder, extending over the outer surfaces of the shoulder spines. There is a less well defined zone of fluorescence just posterior to the siphonal fasciole. These bands and zone, which fluoresce more brightly than the rest of the shell, appear dark in the figure because of the photographic reversal process. They probably represent regions of the shell that were more darkly pigmented in life.

As pointed out to me by Emily Vokes, *Cornulina armigera* from the Eocene Gosport Sand (loc. TU 306, Little Stave Creek, Alabama) fluoresces with a similar pattern. Placed under ultraviolet light after soaking in sodium hypochlorite, specimens show a bright band on the body whorl, anterior to, and including the lower facets of, the shoulder spines. There is another, less well defined, zone of fluorescence just below the suture.

The nearly complete holotype of *T. pittorum* leaves no doubt about the assignment to family Melongenidae. Its overall resemblance to the well-known "crown conchs" (*Melongena,* subgenus *Rexmela* Olsson and Harbison, 1953: type-species *Melongena subcoronata* Heilprin, 1887), of Florida and the Gulf of Mexico, strikes the eye at once. Details of the shell, however, as discussed above, suggest that its closest phylogenetic relationship may not be with *Melongena* but with *Cornulina.* The posteriorly stout body whorl, with its faint sculpture and broad, solid, shoulder spination, strong, umbilicate siphonal fasciole, and the presence of a weak series of spines *posterior* to the premedial constriction are all *Cornulina*-type characteristics. In forms of *Rexmela* that have them, the anterior rows of spines are borne within or anterior to the constriction of the body whorl; they may not be homologous to the weak row of spines in *T. pittorum.*

Eocene species of *Cornulina* — such as *C. minax compressa* Dockery, 1980, illustrated here (Plate 1, figure 5) — differ from *Torquifer pittorum* chiefly in having less tabulate whorls, with more strongly developed anterior spines, and in lacking the elaborate "necklace" between shoulder and suture. *Torquifer pittorum* is larger than any recorded *Cornulina.*

It seems, therefore, that a lineage descended from the Eocene cornulinas and preserving many of their fundamental characters, persisted in the American tropics well into the Neogene.

The function of the bizarre "necklace" of knobs is open to speculation. Its close association with the anal notch — a site of structural elaboration in certain other melongenid shells — suggests a function related to elimination. The necklace may strengthen the shell or divert stress in this region, which might otherwise be a point of attack for shell-crushing predators such as brachyuran crabs (*cf.* Vermeij, 1978, pp. 40-46). It may in addition serve to visually disrupt the spiral pattern of the top of the shell, thus offering some protection against predators hunting by sight.

The species is named for Mr. and Mrs. William D. Pitt, who collected the type

specimen and for many years have favored the California Academy of Sciences with valued donations of fossil and Recent mollusks.

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REVIEWS

THE LANDFORMS OF JAPAN, by Torao Yoshikawa, Sohei Kaizuka, and Yoko Ota. Published by the University of Tokyo Press, Tokyo, Japan, 1981, viii + 22 pp., illus., index, folding map, $39.50 (Distributed by Columbia University Press, New York, New York)

This volume presents the geomorphology of Japan, stressing the growth and dynamic characteristics of the landforms. Previously, no book in an Occidental language has systematically described the distinctive features of the four island arcs comprising the Japanese archipelago. Japanese landforms developed under variable tectonic and denudational conditions in recent geological times. Tectonic and volcanic forces are considered as agents of change, but present-day geomorphological processes are not described in detail except where the explanation of these processes is indispensable to an understanding of the growth features of the landforms. This work will be of major interest to both geographers and geologists, especially to those investigating volcanic phenomena and tectonic activity.

THE UNITED STATES ENERGY ATLAS, by David J. Cuff and William J. Young. published by The Free Press, a division of Macmillan Publishing Co., Inc., New York, New York, 1980, viii + 415 pp., illus., index, $75.00

The amount and distribution of all energy sources, including coal, oil, natural gas, solar power, windpower, and biomass, is described along with hundreds of maps, diagrams, photographs, charts, and tables as illustration of the distribution of these resources. The work is concerned with an attempt to put the present and future status of our energy sources into a comprehensible perspective. It does provide an overview of this vital subject and places it in clearer perspective.

—H.C.S.

REVIEWS

PHILOSOPHY OF GEOHISTORY: 1785-1970, edited by Claude C. Albritton, Jr. Published by Dowden, Hutchinson & Ross, Inc., Stroudsburg, Pennsylvania, 1975, xiv + 386 pp., illus., $37.50

This is volume 13 of the distinguished series *Benchmark Papers in Geology* designed to make the rare and obscure foundation works in the literature of geology more readily and widely available. Though the literature on philosophical aspects of geological thought is vast and highly significant, this most essential element of geohistory has been neglected. No previous compilation of classic writings has been attempted, nor is there any standard work or text on the philosophy of geology. The present volume is a welcome and worthy effort to fill this gap for both the student and the experienced geoscientist.

Professor Albritton has chosen essays or excerpts from the writings of fifteen major contributors to geological thought, ranging from the early works of Hutton, Playfair, and Lyell, to Chamberlin and Gilbert in the late nineteenth century, Davis in the early twentieth century, and contemporary contributors such as Hubbert, Simpson, Hooykaas, and Kitts in the sixties and seventies. His selections are balanced and definitive and fulfill his intent quite well. This book should be read by everyone with a serious interest in the earth sciences.

NORTH AMERICAN GEOLOGY: EARLY WRITINGS, edited by Robert M. Hazen. Published by Dowden, Hutchinson & Ross, Inc., Stroudsburg, Pennsylvania, 1979, xx + 356 pp., 4 figs., index, $35.50

This, the fifty-first volume in *Benchmark Papers in Geology*, comprises a selection of writings on geological subjects dating from the year 1820 and earlier decades in America. Works published with content relating to the earth sciences are little known and largely inaccessible to most geoscientists and historians of science. Their obscurity has led to neglect of their importance and influence on the exploration of and expansion of knowledge of the North American continent. Few early primary works have been reprinted and only one chapter (of fifteen) in Merrill's *The First One Hundred Years of American Geology* was devoted to this early period (1785-1820). Other authors have treated the early history of American Geology in similar brief fashion.

This compilation, together with Hazen and Hazen's recently compiled *Bibliography of American-Published Geology* with nearly 2000 listings for the period 1699 to 1820 (which formed the basis for the present volume), fills the gap in our knowledge of the early geological literature most admirably. Historians of the geosciences will welcome this most important addition to our resources for research and teaching in geohistory.

THE ABYSS OF TIME: Changing Conceptions of the Earth's Antiquity after the Sixteenth Century, by Claude C. Albritton, Jr. Published by Freeman, Cooper & Company, San Francisco, 1980, 251 pp., illus., indexed, $12.75

Professor Albritton predicts that "someday the concept of geological time will be acclaimed as one of the more wonderful contributions from natural science to general thought." In this magnificent work which provides compelling support to his view, he traces changing concepts of the Earth's Age through three centuries from Nicolaus Steno in the 1660's to Arthur Holmes in the 1960's. From the host of observers, he chose to include Steno, Hooke, Burnet, de Maillet, Buffon, Hutton, Smith, Lehmann, Werner, Cuvier, Lyell, Guettard, Desmarest, Agassiz, Darwin, Kelvin, Thomson, Huxley, Chamberlain, Joly, Rutherford, and Holmes, embellished with numerous portraits, illustrations, and quotations from their works and those of others. In the concluding chapter, Professor Albritton addresses the current efforts of "creationists" to overturn evolutionary theory, suggesting that some "recoiling from the fearsome prospect of time's abyss, have toppled backward into the abyss of ignorance." This delightfully and masterfully written book provides most welcome documentation for one of the most basic tenets of the geological sciences.

—H.C.S.

TWO NEW GASTROPOD OCCURRENCES IN THE ECUADORIAN NEOGENE

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During the month of February, 1980, while making a collection of fossils at Quebrada Camarones, Esmeraldas Province, Ecuador (Olsson, 1964, p. 14), William and Lois Pitt discovered two species of Gastropoda that have not previously been reported in the Ecuadorian Neogene.

The Quebrada Camarones locality is a steep cliff along a small stream that empties into the Pacific Ocean about 10 km east of the Esmeraldas River and about 1.5 km inland from the mouth of the stream. Most of the specimens collected were from blocks that had fallen from the upper part of the cliff. The fossils occur in a brown semiconsolidated, highly foraminiferous, pebbly, glauconitic, mudstone matrix.

The geological position of the Quebrada Camarones locality is somewhat in doubt at this time as it is assigned to the Mio-Pliocene Esmeraldas Formation (Olsson, 1964, p. 12) and basel middle-Miocene (N9) Angostura Formation (Bristow, 1976, pp. 193, 196).

The intent of this paper is solely to report the two noteworthy occurrences in the Ecuadorian Neogene and not to evaluate the geological position of the locality. It is felt, however, that with larger and stratigraphic collections from Quebrada Camarones it may be found that there are several horizons and more than one formation occurring there. Recent studies of planktic foraminifera seem to indicate a probable lower Pliocene age for this area.

HARPA AMERICANA Pilsbry, 1922
Text fig. 1

Harpa rosea Lamarck. GABB, 1873, Amer. Phil. Soc., Trans., v. 15, p. 214. (Not *H. rosea* Lamarck, 1816.)

Harpa americana PILSBRY, 1922, Acad. Nat. Sci. Phila., Proc., v. 73, p. 337, pl. 23, fig. 13.

Harpa americana Pilsbry. PERRILLIAT MONTOYA, 1960, Paleontologia Mexicana, no. 8, p. 24, pl. 3, figs. 18-19.

Harpa americana Pilsbry. REHDER, 1973, Indo-Pacific Mollusca, v. 3, no. 16, p. 257-8, pl. 228.

Previous Distribution: This species had only been reported from the Caribbean region prior to this report, Dominican Republic and Veracruz, Mexico. All of these previous reports indicated a geological age of middle Miocene for this species. Recent studies in these areas would seem to indicate a probable lower Pliocene age for this species at these localities.

New Record: A single specimen from the Quebrada Camarones extends the range of this species into the Pacific Region.

CIRSOTREMA TOGATUM
(Hertlein and Strong, 1951)
Text figs. 2,3

Epitonium (Cirsotrema) togatum HERTLEIN and STRONG, 1951, Zoologica, v. 36, p. 89, pl. 3, figs. 1, 5.

Epitonium (Cirsotrema) togatum Hertlein and Strong. KEEN, 1958, Sea Shells Tropical West America, p. 272, fig. 103.

Epitonium togatum Hertlein and Strong. DUSHANE and POORMAN, 1967, Veliger, v. 9, no. 4, p. 424.

Epitonium (Cirsotrema) togatum Hertlein and Strong. OLSSON, 1971, Bull. Marine Science, v. 21, no. 1, p. 89, fig. 77.

Epitonium (Cirsotrema) togatum Hertlein and Strong. KEEN, 1971, Sea Shells Tropical West America, ed. 2, p. 428, fig. 633.

Cirsotrema togatum (Hertlein and Strong). DUSHANE, 1974, Veliger, v. 16 supplement, p. 47-8, figs. 54-5.

Discussion: It is worthy to note here that Hertlein and Strong, (1951, p. 89), in the original description, state that the spiral sculpture consists of seven cords in the interspaces between the axial ribs and numerous fine striae. The Quebrada Camarones specimen has only six cords in the interspaces; however, the paratype, (CAS 9621) also has only six cords in the interspaces.

Previous Distribution: Recent, Guaymas, Sonora, Mexico and south to the Galápagos Islands, Ecuador. Dredged from mud, sand, shell or gravel substrate. Bathymetric range: 32 to 113 m.

New Record: A single specimen from Quebrada Camarones places this species into the fossil record for the first time. It has previously been reported only in the Recent (DuShane, 1974, p. 48).

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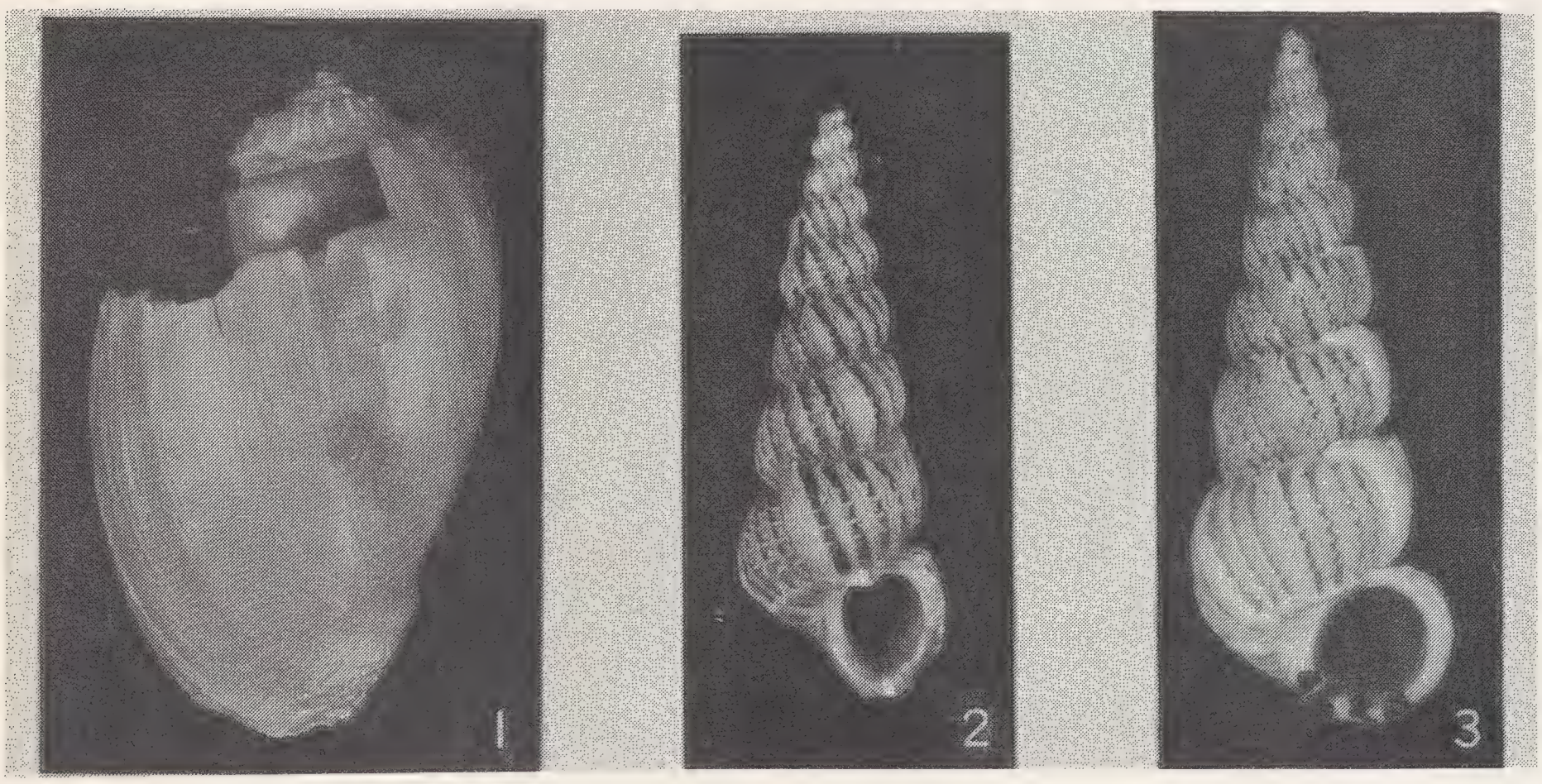

Text figure 1. *Harpa americana* Pilsbry
Height 51.7 mm, diameter 34.9 mm.
Locality: Quebrada Camarones.

Text figures 2-3. *Cirsotema togatum* (Hertlein and Strong)

2. Height 19.5 mm, diameter 7.0 mm.
   Locality: Quebrada Camarones.
3. CAS 9620 (holotype); height 37.5 mm, diameter 13.8 mm.
   Locality: Station 150-D-19, Lat. 23°01′00″ N. Long. 109°27′30″ W., Gorda Banks, Gulf of California, Mexico, dredged in 50 fathoms (91 meters), sand.

NOTES ON THE FAUNA OF THE CHIPOLA FORMATION — XXIII
ON THE OCCURRENCE OF THE GENUS *BASTEROTIA* (MOLLUSCA:BIVALVIA)

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The genus *Basterotia* Mayer *in* Hörnes, 1859, type species *B. corbuloides* Mayer *in* Hörnes, described from the Tortonian (late middle Miocene) of the Vienna Basin, is represented in the fauna of the Burdigalian (late lower Miocene) Chipola Formation of western Florida by two species, one referable to *Basterotia* sensu stricto, the other to the subgenus *Basterotella* Olsson and Harbison, 1953; each represents the oldest presently known occurrence of the respective subgenus in the western Hemisphere. The form described by Aldrich as "*Basterotia ? prima*" from the lower Eocene Wilcox Formation of Alabama is not a member of this genus (see below).

Technically, the name *Harlea* Gray, 1842, is an older generic name for the species presently referred to *Basterotia,* but that name has never been used since the time of its original proposal and must be considered a *nomen oblitum*. Gray's original description (1842, p. 78), ". . . oblong, subquadrate, thin shells, with a sharp keel from the umbo, and conical hinge teeth," is strongly suggestive of the specimens presently referred to *Basterotia*. No species were mentioned in the original description of the genus, which was assigned to the family Corbulidae (p. 91). In 1847, however, Gray (p. 192, no. 640) listed as type "*Corbula* n. s." Subsequently, in 1890 (p. 303), E. A. Smith repeated Gray's 1842 description and then noted: "This diagnosis applies perfectly to the type *marked by Gray himself** as *Harlea,* and this was described the year following by Hinds as *Corbula quadrata.*" In the opinion of the writer this statement has the effect, under Article 69 (a) (ii) of the *International Code of Zoological Nomenclature,* of making Hinds' species the type, by subsequent designation, of *Harlea,* and at the same time, making that genus the senior synonym of *Basterotia*.

Smith went on to add: "Considering the imperfection of Gray's description, and the fact of his not citing any species, I think it would be advisable to ignore his genus *Harlea, although personally I am sure what group he intended to include under that name.*"* Accordingly, he used *Basterotia* for his new species *B. oblonga* [which is almost certainly to be referred to the subgenus *Basterotella*] from the Recent fauna of the Island of St. Helena. Subsequently Lamy (1925, p. 503) noted Smith's observations, but also used the name *Basterotia*. In 1947, Hertlein and Strong (p. 137) cited *Harlea* as the senior synonym of *Basterotia* with the notation "[no species cited]. See E. A. Smith . . ." and then, without further comment used the name *Basterotia*.

Thus, although technically the senior and now valid generic name for those species that have been referred to *Basterotia* since 1859, *Harlea* proves never to have been used in a taxonomic sense since its original proposal in 1842; accordingly it must be considered to be a *nomen oblitum*. The International Commission on Zoological Nomenclature has been requested to suppress the name *Harlea* for purposes of the Law of Priority, but not for those of the Law of Homonymy, and to place that name on the *Official Index of Rejected and Invalid Generic Names in Zoology,* and at the same time, to place the name *Basterotia* on the *Official List of Generic Names,* thus conserving the nomenclatorial usage of some 120 years.

Both *Basterotia* s.s. and *Basterotella* are represented in the Recent faunas of the western Atlantic region; the former by *B. quadrata* Hinds (1843, p. 57) and (?) *B. pustula* Nowell-Usticke (1971, p. 29, fig. 1618)†,

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*Italics by the present writer.

† The systematic position of this small species is uncertain. The published illustration is not adequate to permit determination as to whether it is to be referred to *Basterotia s.s.* or to *Basterotella*. Furthermore the description does not match the figures in that it is said to be "sharply pointed anteriorly instead of being rounded", while the illustration shows a rounded anterior end and a pointed postero-ventral margin resulting from the post-umbonal carination.

the latter by *B. (Basterotella) elliptica* (Recluz) (1850, p. 168) and *B. corbuloidea* (Dall) (1899, p. 885, pl. 88, fig. 2). *Basterotella* is also present in the lowermost Pleistocene Bowden Formation of Jamaica — *B. bowdeniana* (Dall) (1900, p. 1133) — and in the upper Pliocene Caloosahatchee Formation of Florida — *B. floridana* (Dall) (1903, pl. 57, fig. 10).

Basterotia quadrata and its variety or synonym *granatina* (Dall) (1881, p. 109 — as *"Poromya?"*) is present from the coast of South Carolina southward to the State of Alagoas, Brazil (Rios, 1975, p. 220), including Bermuda, the West Indies and the Gulf of Mexico from Texas to Yucatan. It has also been reported from Senegal (Nicklès, 1950, p. 187, text fig. 349 — as *"Anisodonta (Basterotia) quadrata* (Hinds)").

Originally *Basterotia quadrata* was referred to the genus *Corbula*, being described by Hinds from specimens in the Metcalf collection that were without locality data, with the result that there was for some time considerable uncertainty as to the true locus of the species. Hinds for some years had been describing species from the Belcher and Cuming collections that were primarily from Pacific sites. In the paper in which *"Corbula" quadrata* was named there were 21 other species described as *"Corbula;"* all represented in the Belcher and Cuming collections. Nineteen of these twenty-one were cited from eastern and western Pacific Ocean sites, mainly the Panamic and Philippine provinces; one species from the Cuming collection was without locality information, and one, cited as "Cab. Cuming et Metcalf" was from Senegal. In the same paper two new species of *Potamomya* were described; one from the Metcalf collection was cited as "Hab. Brazil . . ." *"Corbula" quadrata* was the only species of *Corbula* cited as being known only from the Metcalf collection. Evidently all three species from that collection came from Atlantic basin localities.

Despite the fact that Recluz (1850, p. 168) had reported Hind's species from Guadeloupe and Hanley (1856, p. 345, pl. 12, fig. 36) had figured the type specimen and cited the locality as the West Indies, Woodring (1925, p. 191), following Dall, referred to *quadrata* as a "Pacific species" as did Durham (1950, p. 95); Olsson and Harbison (1953, p. 97) said that it is from the "Panama-Pacific region." Later, however, Olsson (1961, p. 242) stated that "this species has been cited as a Pacific shell by Dall but without mention of locality station. . . . The occurrence of this species in the eastern Pacific . . . remains unverified." The Pacific species, according to Keen (1971, p. 145) is *Basterotia (Basterotia) peninsularis* (Jordan) (1936, p. 147, pl. 18, figs. 11, 12 — as *"Anisodonta"*), originally described from the Pleistocene of Baja California, and found living from eastern Oaxaca, Mexico, to the Galápagos Islands.

It is difficult to arrive at any conclusions as to the paleoecologic significance of the occurrence of *Basterotia* and *Basterotella* in the Chipola fauna. The data on the Recent western Atlantic species seem suspect, for in every case where authors cite the nature of the material and the depth from which it was obtained, the latter information proves to be based upon single valves. The extreme depth range for *B. quadrata* of 6 to 640 fathoms cited by Dall (1889, p. 70), and following him by Johnson (1934, p. 57) and Abbott (1974, p. 476), who lists 5 to 640 fathoms, proves to be based, in the case of the deeper record, on a single valve (see Dall, 1886, p. 316). This may well have been transported in the intestines of a mollusc-eating fish, or by some other means from waters of much shallower depth. Most authors tend to cite more shallow depths; the 5 fathoms indicated by Abbott *(sup. cit.)* apparently is based upon his 1958 (p. 137) record of "a single left valve . . . dredged in 30 feet of water near the Main Channel, North Sound, Grand Cayman" Island. Rios (1976, p. 220) lists the species from two dredging stations off the northeast coast of Brazil, at 20 to 50 meters, sandy bottoms, but does not indicate whether or not the records are based upon living material. Odé (1973, p. 79) lists *B. quadrata granatina* from one locality off the Texas coast at 40 fathoms, sand and mud bottom, but again with no indication as to the nature of the material.

A similar situation exists with respect to the eastern Pacific *B. peninsularis* (Jordan); Hertlein and Strong (1947, p. 137) note: "one fairly large valve . . . was found in the beach drift at Corinto, Nicaragua. Another very small valve . . . was dredged in 7 fathoms at Port Guatulco, Mexico." Keen (1971, p. 145) states: "Living, Port Guatulco, Mexico, to Galápagos Islands, intertidally and to depths of 13 meters." The Port Guatulco locality, and 13 meters depth undoubtedly are based upon the Hertlein

and Strong material, the "intertidally" may refer to the Galápagos occurrences. In this connection it is of interest to note that Keen, in her discussion of *Basterotia (Basterotella) hertleini* Durham says that the species occurs "intertidally, nestling in crevices and offshore to 46 m, . . ."

The writer suggests that the phrase "nestling in crevices" may be an answer to the problem of the scarcity of records of living individuals of both *Basterotia* and *Basterotella*. Only those specimens that had been washed out or had been removed from the crevices by predators would be found by dredging, and, with the relatively small ligamental area the valves would be rather easily separated during their removal. It is also significant that none of the 76 valves of the two Chipola species here described were found in association with its opposite. The Chipola occurrences are shown in Table 1.

Potamides suprasulcatus (Gabb) and *Terebralia dentilabris* (Gabb) (see Hoerle, 1972, p. 17, pl. 1, figs. 7, 8 and p. 20, pl. 1, figs. 9-11, respectively), plus many blocks and boulders composed of much-bored fragments of coral and of calcareous sandstone. The type specimen of *Concholepas drezi* E. H. Vokes (1972, p. 32, text fig. 1a-c) is from this locality, which was certainly in relatively shallow water not too distant from the mouth of a fresh-water stream.

Locality TU 555, near the top of the exposed section on the Chipola River has the largest representation of the present species, 27 valves, and again has abundant colonial coral specimens, all much bored by species of bivalves. Associated are a new species of *Turbo*, *Potamides suprasulcatus*, *Terebralia dentilabris*, the second and only other known specimen of *Concholepas drezi*, together with numerous examples of *Smaragdia chipolana* (Dall) (1892, p. 422, pl.

Table 1

Tulane Univ. localities	*Basterotia (Basterotia) ambona*		*Basterotia (Basterotella) miocenica*	
	right valves	left valves	right valves	left valves
459	1	0	2	3
546	1	0	1	2
547	0	0	1	1
555	6	11	1	9
818	1	1	0	0
819	1	1	0	0
824	0	1	0	0
830	1	1	3	5
950	0	0	1	0
1021	0	0	0	1
1048	6	3	4	0
1196	6	6	1	4
	23	24	14	25

In accord with the suggestion that these forms may have a nestling habit is the fact that all of those localities from which more than three or four valves were secured show features that indicate close proximity to shallow-water or coral reef environments. The extreme, perhaps, is TU 459, where two species of *Donax* constitute the most abundant element of the fauna. Associated are six valves representative of the two species here described plus numerous specimens of the fresh-water gastropod genus *Planorbis*, a number of large valves of *Ostrea haitensis* Sowerby, specimens of

23, fig. 19 — as "*Neritina*"). The modern representatives of *Smaragdia* are abundant on turtle grass from low tide to about 10 fathoms.

Locality TU 830, at the base of the Chipola Formation on Tenmile Creek has ten valves of the *Basterotia* species. At this site the fossils occur adjacent to an irregular, eroded and channeled contact with the underlying lower Miocene Chattahootchee Formation, a tan, usually sandy, dolomitic limestone, boulders of which, together with some heads of coral, occur at the immediate contact.

At TU 1196, on Farley Creek from which we have eleven valves, it appears that we are again near the base of the formation, but the actual contact has not been observed. There are, however, numerous rather large, much-bored blocks of calcareous material obviously derived from the Chattahootchee Formation, numerous heads and fragments of coral, some having rounded pebbles of a milky quartzite up to about one inch in diameter incorporated within them. Here also we find specimens of the new species of *Turbo*, together with *Smaragdia chipolana* and large valves of *Ostrea haitensis*.

Family SPORTELLIDAE Dall, 1899
[+ BASTEROTIIDAE Cossmann, 1909]

Genus BASTEROTIA Mayer *in* Hörnes, 1859

Harlea GRAY, 1842, Synop. Contents Brit. Mus., ed. 44, p. 78 (genus without species). Type species: *Corbula quadrata* Hinds, 1843, by subsequent designation [ICZN Art. 69(a) (ii)], Smith, 1890, see discussion above.

Eucharis RECLUZ, 1850, Journ. de Conchyl., v. 1, p. 167. Type species: *Corbula quadrata* Hinds, 1843, by original designation [non *Eucharis* Latreille, 1804 (Hymenoptera), etc.].

Basterotia MAYER *in* HÖRNES, 1859, Verhandl. k. k. Zool.-Bot. Gesell. Wien, v. 9, p. 71. Type species: *Basterotia corbuloides* Mayer *in* Hörnes*, by monotypy.

Basterotia s.s. includes moderately small subquadrate species of corbuliform aspect, with however, a sharply angled, usually carinate, posterior ridge extending from immediately behind the prosogyrate umbo to the postero-ventral margin. The surface is marked by fine concentric growth lines that may become coarsened and somewhat laminate toward the ventral margin, and by fine to coarse granulations. On the species here described, and to a lesser extent on those specimens of *B. quadrata* (Hinds) available for study, these granulations are most strongly developed on the more anterior portion of the right valves, tending to weaken posteriorly, becoming almost, or entirely absent adjacent to the posterior umbonal ridge, but being relatively strong again on the posterior slope. The ligament is external, situated on a rather strong, inflated, almost tooth-like nymph. The hinge is marked by one relatively large and more or less hook-shaped cardinal tooth in each valve; that of the right valve separated from the nymph by a narrow gap, with a well-developed cardinal socket immediately anterior to it, while that of the left valve is anterior to the socket and is supported anteriorly by a somewhat projecting margin of the valve itself. The pallial line is entire.

Superficially corbuloid in size and general shape, species referable to *Basterotia* may be distinguished by their external ligament mounted on a strong inflated nymph, by the absence of a chondrophore on the hinge plate and by the fact that the cardinal teeth are reversed in position from those in the Corbulidae with that of the right valve posterior to the socket and that of the left anterior to it.

Insofar as can be determined the following is the first species referable to *Basterotia* sensu stricto to be described from the western Atlantic Tertiary faunas. As noted above, *Basterotia ? prima* Aldrich (1921, p. 20, pl. 3, figs. 1-3) from the Wilcox, lower Eocene of Alabama, is not a member of this genus; the large anterior ventral gape, median umbo-ventral depression, the raised border of the anterior adductor that is "buttresses to the hinge plate," as well as the details of the hinge including, apparently, the absence of a cardinal tooth in the left valve are all characters that distinguish it from *Basterotia*. Dall's (1900, p. 1133) *Anisodonta (Basterotia) bowdeniana* from the basal Pleistocene Bowden beds of Jamaica, which was referred to *Basterotia* s.s. by Woodring (1925, p. 101, pl. 26, figs. 9, 10) is a member of the subgenus *Basterotella*.

*It should be noted that although most modern authors, including Chavan in the *Treatise on Invertebrate Paleontology* (p. N540), cite the author of this species as "Hörnes," Hörnes himself, and a number of subsequent authors, including Fischer (1887, p. 1076), Dall (1886, p. 306; 1900, p. 1132), Lamy (1925, p. 503), etc., attribute it to Mayer.

BASTEROTIA (BASTEROTIA) AMBONA
H. E. Vokes, n. sp.
Text figures 1-3

Diagnosis: Shell relatively small, subquadrate corbuliform, inflated, with a strongly carinated angulation extending from immediately behind the prosogyrate umbo to the postero-ventral margin, the angulation being stronger, more carinated and pronounced during the younger

stages of shell growth (see pl. 1, fig. 3), generally weakening and losing its pronounced carination in the ventral, adult stages. Umbo situated approximately at the anterior third of the total shell length; anterior end rounded and passing gently into the relatively straight ventral margin; posterior margin straight to slightly arcuate, subangulate to sharply rounded at the postero-ventral corner, the degree of angulation reflecting the relative strength of the ventral portion of the umbonal ridge. Surface marked by concentric growth rugae of varying strength, occasionally being sufficiently raised to resemble rounded concentric ribs; superimposed upon these, especially in the right valve, strong, pustulose granulations most numerous on the anterior half of the valve, becoming weak, almost absent, immediately in front of the posterior umbonal angulation, and then being again well-developed on the posterior end. Hinge typical of the genus; inner valve margins smooth, except, in some specimens, the posterior portion of the dorsal margin finely denticulated, apparently by marginal pustulations similar to those on the outer surface; pallial line entire, adductor scars nct prominent, the anterior extended dorsally into the umbonal portion of the valve behind the hinge area.

Holotype, USNM 298649; length 11.6 mm, height 9.5 mm, diameter (right valve) 3.3 mm; locality TU 555.

Paratype, USNM 298650; length 10.5 mm, height 9.4 mm, diameter (left valve) 3.3 mm; locality TU 1196.

Paratype, USNM 298651; length 6.4 mm, height 5.7 mm, diameter (right valve) 1.7 mm; locality TU 1196.

Remarks: Basterotia ambona differs from *B. corbuloides,* the type species of the genus — insofar as can be determined from the description and illustrations given by Hörnes (1859, p. 40, pl. 3, figs. 11a-g), no specimens being available for comparison — in being somewhat smaller, proportionately shorter as compared to the height, less strongly inflated and in lacking the median depression in front of the carinate posterior umbonal ridge that results in a shallow concavity in the ventral margin of the Vienna Basin species. The Recent *B. quadrata* and *granatina* are smaller than *B. ambona,* less strongly pustulated, and have a more arched postero-dorsal margin with the umbo relatively more anterior in position, approximately at the anterior quarter of the valve length. The specific name is from the Greek "ambon" meaning a ridge or crest.

The Tulane University collections from the Chipola Formation contain 47 valves (23 right and 24 left) of this new species (see Table 1).

Subgenus BASTEROTELLA Olsson & Harbison, 1953

Basterotella OLSSON and HARBISON, 1953, Acad. Nat. Sci. Phila., Mon. 8, p. 97. Type species: *Pleurodesma floridana* Dall, 1903, by original designation.

The subgeneric name *Basterotella* was proposed for forms "with the nymphal ridge shorter and bearing a small resilial scar on its lower or inner side," (Olsson, 1961, p. 243). They also have a rounded or angled, but non-carinate, posterior umbonal ridge. The type species, as figured by Olsson and Harbison (1953, pl. 9, fig. 1a), shows well-developed surficial granulation on the right valve, and Olsson, in the original description of the subgenus states that it is "Like *Basterotia* in . . . surface granulation . . .". Most species, however seem to have this granulation but weakly developed, and in some it appears to be absent. Nevertheless, Olsson (1961, p. 243) and Abbott (1974, p. 476) err when they state that species referable to *Basterotella* lack surface granulation.

BASTEROTIA (BASTEROTELLA) MIOCENICA H. E. Vokes, n. sp.

Text figures 4-6

Diagnosis: Shell relatively small, elongate-quadrate in shape, inequilateral with umbo approximately at the anterior fourth of the total length; the short anterior end broadly and regularly rounded, the more elongate posterior with almost parallel dorsal and ventral margins and rounded end; valves moderately well inflated with a rounded to subangulate, non-carinated posterior umbonal ridge, ornament of concentric growth increments of varying strength, forming a somewhat irregularly concentric pattern, and of microscopic surficial granulations stronger on the right valves where they usually extend to about mid-length of the valve; in left valves, where present; occurring only on the anterior fourth of the length. Hinge essentially that of the genus *Basterotia* with an exceedingly small resilial scar; inner valve margins smooth, that of the dorsal side tending to be broadly and regularly arched from the nymph all the way to the posterior end in contrast to the parallelism when viewed externally. Anterior adductor scar elongate ovate, a little impressed and with a low rounded ridge adjacent to its posterior side; posterior scar almost twice as large as the anterior, rounded and not impressed.

Holotype, USNM 298652; length 11.4 mm, height 7.9 mm, diameter (right valve) 3.2 mm; locality TU 555.

Paratype, USNM 298654; length 10.8 mm, height 7.6 mm, diameter (left valve) 3.0 mm; locality TU 1196.

Paratype, USNM 298653; length (slightly incomplete) 10.2 mm, height 7.9 mm, diameter (left valve) 2.5 mm (a variant with inflated umbonal region giving a rounded outline); locality TU 1196.

Remarks: Basterotia (Basterotella) miocenia differs from *B. (B.) bowdeniana* (Dall), the type and only known specimen of which, a right valve with broken ventral margin, was figured by Woodring (1925, p. 191, pl. 26, figs. 9, 10 — as *Basterotia* s.s.), in having a somewhat broader, less acute umbo, apparently in response to a more sharply angulate posterior-ventral ridge in the Bowden species. The anterior end of the Chipola form is broadly and regularly rounded, lacking the antero-dorsal angulation shown in the Woodring illustrations. Dall's measurements, "length 10.5 the diameter about 5 millimeters" suggest that the Bowden shell is proportionately more inflated. The Recent *B. (B.) elliptica* (Recluz) is essentially similar in shape, but is smaller. Abbott (1974, p. 476) gives the length as 5 to 9 mm; the largest of the three specimens in the Tulane University collection from the northern coast of the Yucatan Peninsula has a length of 5.4 mm and a height of 3.3 mm. These have the umbo somewhat more anterior in position, and are less inflated with a somewhat lower, more rounded postero-ventral "ridge". Whether or not these features are a reflection of the small size of the possibly immature specimens cannot be determined without additional material. It is of interest that all of these small shells show microscopic granulations on the valve surface, over all of the anterior half in the right valve, but on the anterior fourth only, in the left valves.

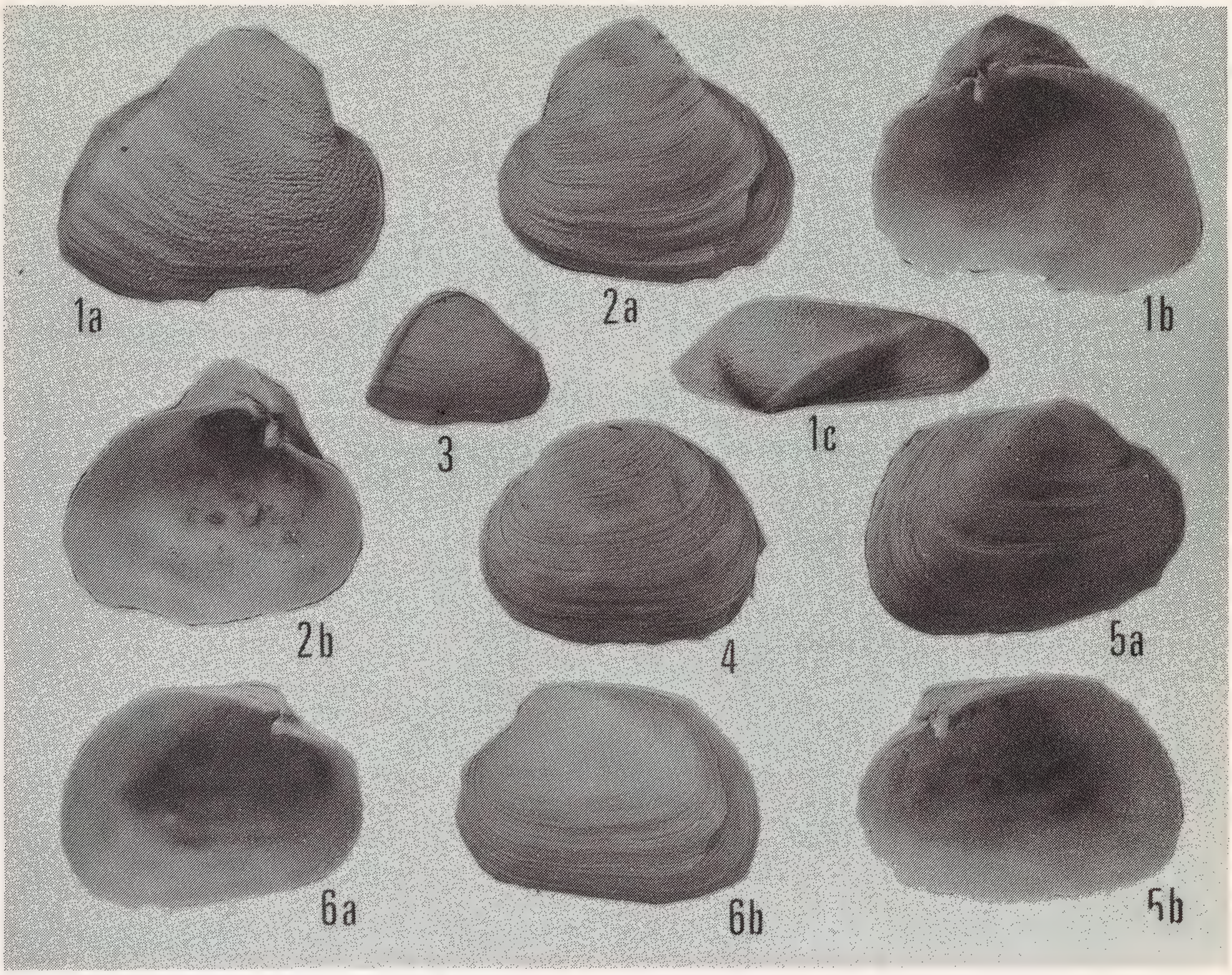
Anisodonta corbuloidea Dall (1899, p. 885, pl. 88, fig. 2), which Abbott (1974, p. 476) referred to *Basterotia (Basterotia)*, appears to be more correctly referred to *Basterotella*. Judging from Dall's figure of the interior of the valve the shell is more elongate and rectangular in outline than *B. (B.) miocenica,* and has a considerably lower umbo; it also is a smaller form, Dall gives the length as 6.5 mm, and also notes that the surface is "*microscopically sagrinate.*" Although the specific name *corbuloidea* is similar to that of *Basterotia corbuloides* the type species of the genus, it is not to be considered as a homonyn of the latter. The termination *-oides* (= "like") makes the type species name a noun of the feminine gender, while *-oidea* as used by Dall, is an adjective in the feminine gender. The International Code of Zoological Nomenclature, Article 57(b) (i) clearly limits to adjectival forms the disregarding of differences in termination due solely to gender.

The Tulane University collections contain 39 valves (14 right, 25 left) of *B. (B.) miocenica* from nine Chipola localities (see Table 1).

LOCALITY DATA

The following Tulane University fossil localities in the Chipola Formation, Calhoun County, Florida, have yielded specimens referable to the genus *Basterotia:*

459. Chipola River, east bank about 1500 feet upstream from the mouth of Taylor Lake Branch (NW¼ Sec. 29, T1N, R10W).
546. Tenmile Creek, north bank about 1.75 miles west-northwest of mouth of the creek at Bailey's Ferry (SW¼NE¼ Sec. 12, T1N, R10W).
547. Chipola River, west bank about 2000 feet upstream from mouth of Fourmile Creek (SW¼ Sec. 29, T1N, R9W).
555. Chipola River, east bank about 1000 feet above mouth of Fourmile Creek (SW¼ Sec. 29, T1N, R9W).
818. Farley Creek, south bank 0.1 mile west of bridge at Florida Highway 275 (SW¼ Sec. 21, T1N, R9W).
819. Farley Creek, south bank 0.2 mile west of bridge at Florida Highway 275 (SW¼ Sec. 21, T1N, R9W).
820. Farley Creek, immediately upstream from bridge at Florida Highway 275 (SW¼ Sec. 21, T1N, R9W).
824. Farley Creek, north bank about 0.5 mile east of bridge at Florida Highway 275 (SE¼ Sec. 21, T1N, R9W).
830. Tenmile Creek, north bank at power line crossing, about 1.3 miles west-northwest of mouth of creek at Bailey's Ferry (SE¼SE¼ Sec. 12, T1N, R10W).
950. Chipola River, west bank, about 2000 feet above mouth of Farley Creek (NE¼SW¼ Sec. 20, T1N, R9W).
1021. Tenmile Creek, north bank at north end of first meander upstream from TU 546, about 0.45 mile east of bridge on Florida Highway 73 (SE¼NW¼ Sec. 12, T1N, R9W).
1048. Farley Creek, about 0.6 mile east of bridge on Florida Highway 275 (SW¼NE¼ Sec. 21, T1N, R9W).
1196. Farley Creek, north bank, about 0.65 mile east of bridge on Florida Highway 275 (SW¼NE¼ Sec. 21, T1N, R9W).



Text figures (all ×3)

1 - 3. *Basterotia (Basterotia) ambona* H. E. Vokes, n. sp.

1. Holotype, USNM 298649; length 11.6 mm, height 9.5 mm, diameter 3.3 mm. Locality TU 555.
2. Paratype, USNM 298650; length 10.5 mm, height 9.4 mm, diameter 3.3 mm. Locality TU 1196.
3. Paratype, USNM 298651; length 6.4 mm, height 5.7 mm, diameter 1.7 mm. Locality TU 1196.

4 - 6. *Basterotia (Basterotella) miocenica* H. E. Vokes, n. sp.

4. Paratype, USNM 298653; length 10.2 mm, height 7.9 mm, diameter 2.5 mm. Locality TU 1196. Variant with inflated postero-dorsal region resulting in rounded outline.
5. Paratype, USNM 298654; length 10.8 mm, height 7.6 mm, diameter 3.0 mm. Locality TU 1196.
6. Holotype, USNM 298652; length 11.4 mm, height 7.9 mm, diameter 3.2 mm. Locality TU 555.

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October 28, 1981

NOTES ON THE FAUNA OF THE CHIPOLA FORMATION — XXIV
THE GENUS *ASTARTE* (MOLLUSCA:BIVALVIA)

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In 1936 Gardner reported the presence of the bivalve genus *Astarte* in the fauna of the Chipola Formation of Calhoun County, Florida. Based upon a single, worn, right valve that had been sent her by the Florida Geological Survey, and said to have been collected from "one-fourth mile below Bailey's Ferry, Chipola River, Calhoun County, Florida;" the form was described and figured (1936, p. 20, pl. 4, fig. 1) as "*Astarte (Ashtarotha)* species." As noted by Gardner this was the "first record of this typically cold-water genus in the Chipola of Florida."

The Tulane University collections presently include 137 single valves, all from localities within the lower part of the Chipola Formation; 123 of these are from the beds exposed along Tenmile Creek and 12 from the Chipola River outcrops. Only a single small valve has been found from the Farley Creek section. Five of the 12 specimens from the Chipola River area are from TU 810, which is approximately one-fourth mile below the site of the old Bailey's Ferry and presumably the site from which the specimen reported by Gardner was collected. All five specimens are much worn, as are the majority of the specimens in the collection, and apparently had been subjected to preburial transportation.

Family ASTARTIDAE d'Orbigny, 1844

Genus ASTARTE J. Sowerby, 1816

Astarte J. SOWERBY, 1816, Mineral Conchology of Great Britain, v. 2, p. 85.

Crassina LAMARCK, 1818, Hist. Anim. s. Vert., v. 5, p. 554* [monotype:*Crassina danmoniensis*=*Venus danmoniensis* Montagu, 1807=*V. scotica* Maton and Rackett, 1807].

Type species, by original designation:*Venus scotica* Maton and Rackett (=*Pectunculus sulcatus* Da Costa, 1778, var. *scotica* Maton and Rackett, 1807). Recent; coast of Scotland.

*Through an obvious typographical error pages 551 through 560 are repeated in volume 5 of Lamarck's work; the genus *Crassina* is described on the first usage of the number 554.

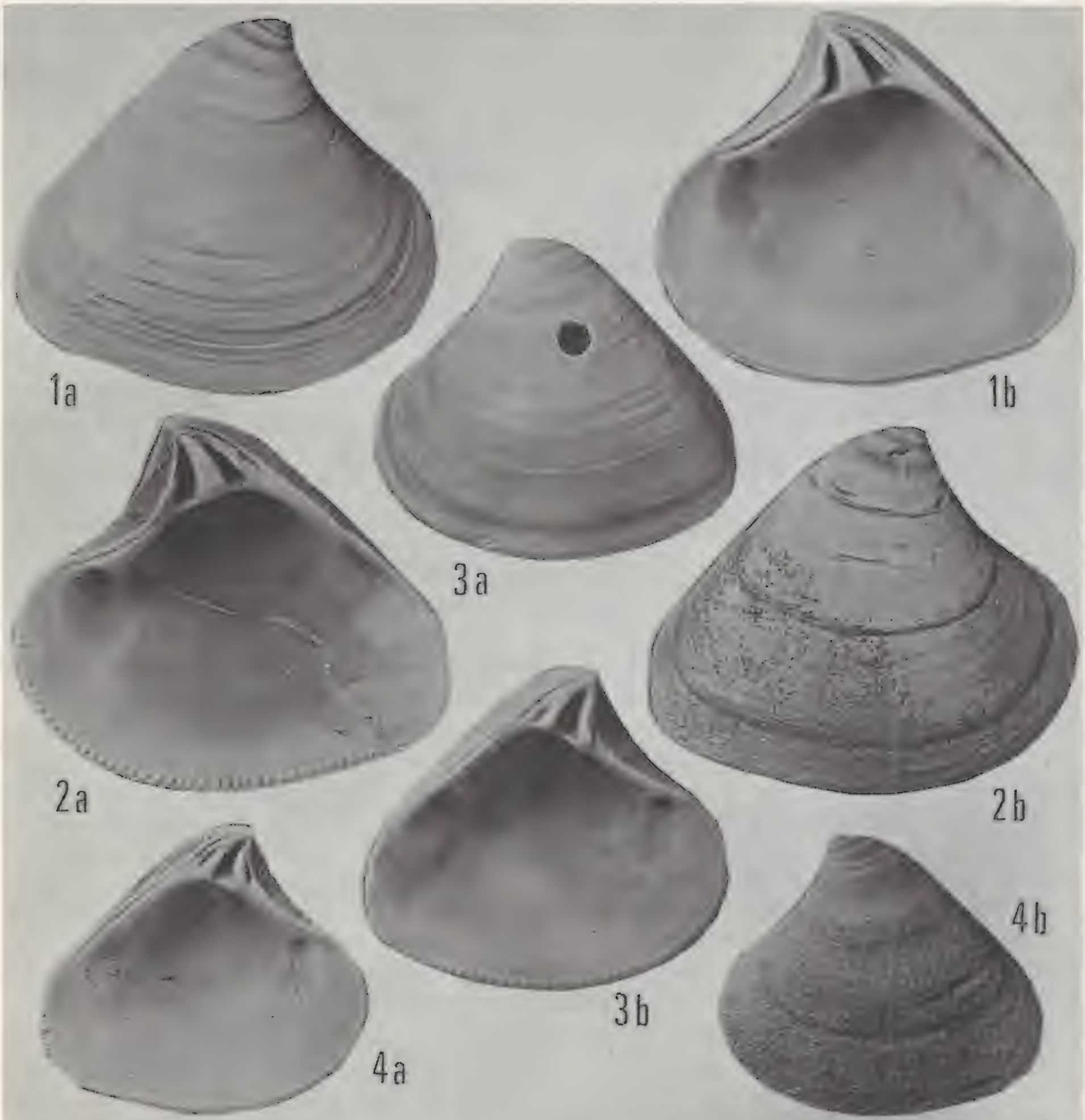
Subgenus ASHTAROTHA Dall, 1903

Ashtarotha DALL, 1903, U.S. Natl. Mus., Proc., v. 26, p. 936.

Type species, by original designation, *Astarte undulata* Say, 1824. "Maryland" [= Pliocene, Yorktown Formation, mainly Virginia and North Carolina; see Gardner, 1948, p. 57, pl. 12, figs. 25, 31].

ASTARTE (ASHTAROTHA) PANSYRTA
H. E. Vokes, n. sp.
Text figures 1-4

Description: Shell relatively small, subtrigonal in outline, with prominent, flattened, acute and slightly prosogyrate umbones; shape of the dorsal half of the valve profoundly affected by the moderately narrow, elongate-lanceolate and deeply excavated lunule and the straight, flattened escutcheon; anterior dorsal slope concave, broadly and regularly rounding through the anterior end into the ventral margin. Latter more convex anteriorly, becoming almost straight posteriorly and subangulately rounding into the short, slightly convex posterior end. This, in turn, curving sharply into the almost straight posterior dorsal margin, which is, however, broadly arched in the umbonal area. External sculpture, confined to flattened surface of the umbones, of three to eight, usually five, subequal and subequally spaced rounded concentric elevations, with dorsal slope steeper than ventral one; remainder of valve surface marked only by concentric growth lines and, in some specimens with inconspicuous, low, rounded undulations near the ventral margin. Ligament marginal, short, approximately as long as the adjacent low and feeble posterior cardinal tooth of the right valve, and separated by a low nymphal ridge from the shallow corresponding socket on the left valve; median right cardinal stout, projecting, cuneiform; right anterior cardinal obsolete; left valve with relatively strong and subequal anterior and median cardinals divergent on each side of a deep sub-umbonal socket for the reception of the median right cardinal; left posterior cardinal obsolete. Margins of hinge teeth of both valves transversely striated. Anterior lunular margin of the right valve and posterior escutcheonal margin of the left feebly grooved to receive the corresponding beveled edges of the opposite valves. Adductor scars moderately large, well-marked and impressed, especially at their dorsal ends, the anterior reniform, the posterior ovate in outline; small, pit-like depressions for the reception of the retractor muscles on the inner, sub-lunular



Text figures (all ×3)

1. USNM 298645. Holotype (right valve); height 14.6 mm, length 16.3 mm, diameter 3.8 mm; form with smooth ventral margin.
2. USNM 298646. Paratype A (right valve); height 14.4 mm, length 16.9 mm, diameter 4.1 mm; form with crenulate ventral margin.
3. USNM 298647. Paratype B (left valve); height 12.8 mm, length 14.0 mm, diameter 3.9 mm; form with crenulate ventral margin.
4. USNM 298648. Paratype C (left valve); height 11.3 mm, length 12.8 mm, diameter 3.0 mm; form with smooth ventral margin.

(All specimens from locality TU 830)

surface; pallial line simple, distant from the valve margins which may, or may not, be crenulate.

Type locality: TU 830. Tenmile Creek, north bank at power line crossing, about 1.3 miles west-northwest of mouth of creek at Bailey's Ferry (SE¼SW¼ Sec. 12, T1N, R10W), Chipola Formation, Calhoun County, Florida.

Remarks: In her original presentation Gardner noted that the Chipola specimen seemed to be "related to the Choctawhatchee forms rather than to those from the later Alum Bluff." The additional, better preserved specimens now available confirm this observation and the writer is of the opinion that the Chipola species is probably ancestral to *Astarte (Ashtarotha) floridana* Dall, 1903 [p. 1493, pl. 57, fig. 19: as "*Astarte (distans* var. ?) *floridana*"]. The latter is a much larger species (specimens in the Tulane University collections attain lengths up to 29 mm) and has a much less concave antero-dorsal margin adjacent to the lunule, resulting in a broader and less attenuated umbone. In addition, the posterior margin is proportionally shorter and subangulate rather than slightly convex as in the present new species.

The specific name is derived from the Greek term "pansyrtos" (swept together, accumulated) and is applied in allusion to the fact that specimens in the collection show much evidence of having suffered pre-burial transportation.

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October 28, 1981

REVIEW

THE CHEROKEE EXCAVATIONS: Holocene Ecology and Human Adaptations in Northwestern Iowa, edited by Duane C. Anderson and Holmes A. Semken, Jr. Published by Academic Press, New York, London, Toronto, Sydney, and San Francisco, 1980, xvi + 277 pp., illus., index, $23.00

The Cherokee (Iowa) Project revealed the presence of three major mid-Holocene cultural horizons in stratified fan deposits. Minor changes in the tool assemblages and subsistence patterns of the hunting cultures of each horizon represent the cultural shift from Late Paleo-Indian to the Prairie Archaic tradition. An inter-disciplinary team of archaeologists, geologists, and paleontologists, funded by National Science Foundation grants to The University of Iowa, the Iowa Geological Survey, and The University of Wisconsin, investigated this site and formed the basis for this volume. One chapter is devoted to the geology of the Cherokee Site, defines and describes the stratigraphic units within the alluvial fan sequence, presents absolute and relative time relationships, and interprets the sedimentary environments. Also, a model of humid alluvial fan sedimentation is proposed. Three other chapters are concerned with climatic interpretations and reconstructions based on faunal and floral content and on other environmental factors revealed by the studies of the team of scientists. The main value of this volume to geologists is as a model of how geological and archaeological interpretations can be interrelated and advantageous to both disciplines.

—H.C.S.

PALEONTOLOGICAL NOTE

BOLIVINA (BRIZALINA) HAMANI, A NEW NAME FOR *BOLIVINA MEXICANA* CUSHMAN, 1926 *NON* CUSHMAN, 1922 (FORAMINIFERIDA)

KENNETH L. FINGER
CHEVRON OIL FIELD RESEARCH COMPANY
LA HABRA, CALIFORNIA

Cushman (1926, p. 81) erected *Bolivina mexicana* on specimens from the lower Oligocene Alazan clays of Veracruz, Mexico. Earlier Cushman (1922, p. 47) had named *Bolivina subaenariensis* var. *mexicana* for Recent specimens collected in the northern Gulf of Mexico. According to the *International Code of Zoological Nomenclature*, Art. 45(e), a varietal designation made prior to 1961 is "not to be interpreted as an express statement of either subspecific or infrasubspecific rank." As a result, Cushman's Oligocene species was not considered a primary junior homonym (as defined by ICZN Art. 57) until Parker (1954) promoted the Recent "variety" to subspecies rank. Subsequent Gulf of Mexico workers either have retained this subspecific ranking (*e.g.*, Bandy, 1956; Akers and Dorman, 1964; Pflum and Frerichs, 1976) or elevated it to species level (*e.g.*, Andersen, 1961).

The brizalinid character of these two species is considered here as subgeneric *sensu* Gramann (1966, p. 439). In compliance with the Law of Homonymy (ICZN Art. 53), *Bolivina (Brizalina) subaenariensis mexicana* Cushman, 1922 is retained while *Bolivina (Brizalina) hamani* is proposed herein to replace *Bolivina (Brizalina) mexicana* Cushman, 1926. Cushman (1926) also named two "varieties" of his *Bolivina mexicana* from Veracruz; these three epithets are herein recognized as *Bolivina (Brizalina) hamani hamani* Finger, *nom. nov.*, *Bolivina (Brizalina) hamani aliformis* Cushman, 1926, and *Bolivina (Brizalina) hamani horizontalis* Cushman, 1926.

Bolivina (Brizalina) hamani is named in honor of Dr. Drew Haman, Senior Research Geologist, Chevron Oil Field Research Company, La Habra, California.

I thank D. Haman and R. W. Huddleston for their assistance and reading of the manuscript, and Chevron Oil Field Research Company for publication permission.

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THE MAKING OF A GEOLOGIST — IN THE FOOTSTEPS OF DARWIN IN SOUTH AMERICA

HAROLD E. VOKES AND EMILY H. VOKES
TULANE UNIVERSITY

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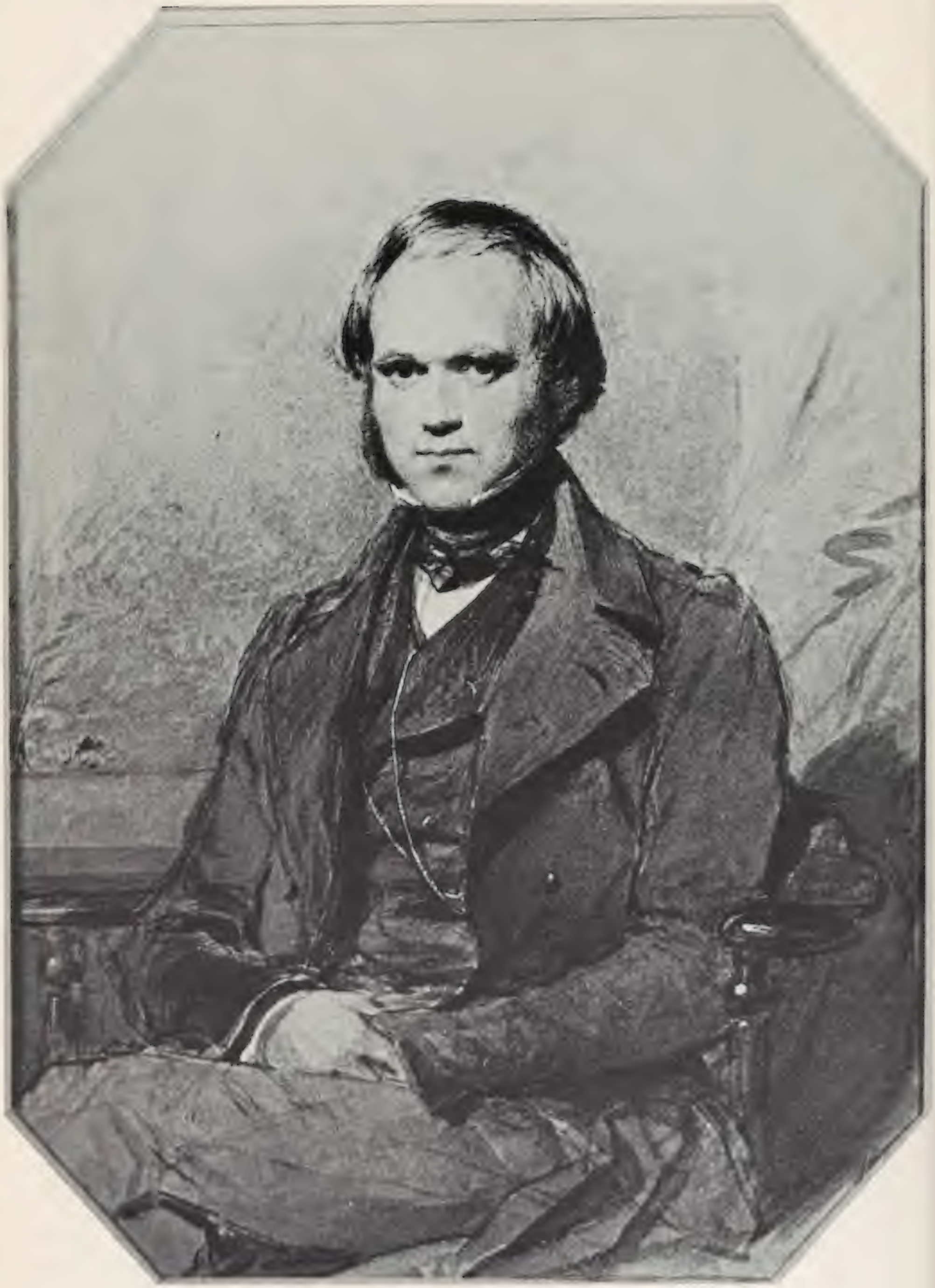

CHARLES ROBERT DARWIN
12 February 1809 — 19 April 1882

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Almost everyone is acquainted with the name of Charles Darwin, and is aware of his enormous contributions to the life sciences. These resulted, in large measure, from his experiences during the five years he served as naturalist on HMS *Beagle* during its long voyage around the world. Not so well known, however, are his considerable geological contribution, set forward in his "Journal of Researches into the Geology and Natural History of the Various Countries Visited by the *Beagle*" (1839), in his "Structure and Distribution of Coral Reefs" (1842), and his "Geological Observations on South America" (1846).

To appreciate the real significance of Darwin's geological observations fully, one must view them in the context of the state of knowledge of the science that existed when they were made. The voyage of HMS *Beagle* began in 1831. It was during this year that Adam Sedgwick, President of the Geological Society of London, made a most effective speech as he awarded the first Wollaston Medal of that Society to William Smith, acclaiming and greeting him as the Father of Stratigraphic Geology. Then, in the summer months of the same year, Sedgwick began the program of field work in northern Wales that led to his proposing the Cambrian System in 1835. His field assistant during that first summer was a young man just graduated from Cambridge University-Charles Darwin.

1831 — Stratigraphy was in its infancy. The geologic time scale consisted of only three units: "Primary," "Secondary," and "Tertiary," with finer subdivisions just beginning to be considered. Those named were of local significance, with such terms as "The Old Red Sandstone," "Carboniferous Strata," and "Liassic," being applied in the areas known to Darwin but not yet extended elsewhere. The scientific thinking of the day was dominated by concepts of the "Universal Deluge" and of an earth that had been created, according to Bishop Ussher, in 4004 B.C.

To bring it closer to home, James Hall was just beginning his Senior year at Rennselaer Polytechnic Institute. Timothy Abbott Conrad was studying fossils and preparing engravings on stone with which to illustrate the first parts of his work on fossil shells of the Tertiary Formations of North America, which began appearing in 1832 and finished in 1837. When this work was republished in 1893 by Professor G. D. Harris, he referred to it as "the beginning of systematic research into this period of our continent's history." Geology as a science was in its infancy.

But to come back to Darwin — when he returned to his home following his field season with Sedgwick on 29 August, 1831, he found a letter from his old Cambridge professor, mentor, and friend, John Henslow, that bore with it an offer to Darwin of the post of naturalist [unpaid] for the forthcoming voyage of the *Beagle*. Despite objections from his family, Darwin went to London and, early in September, he met with Captain Robert Fitzroy and the plans were underway. While in London, Darwin attended some of the parades and festivities attendant upon the coronation of William IV as king of England [William was the father of Victoria]. But mainly he was engaged in making preparations for the departure of the ship, then scheduled for late October. Darwin went on board on 24 October, but with delays the voyage did not begin until 27 December. One good aspect of this was that Darwin had time to receive, as a present from Henslow, the first volume of Lyell's "Principles of Geology" — just off the press.

Figure 1. "Pão de açucar," or "Sugar-loaf," Rio de Janiero, Brazil.

Figure 2. Ilha Grande, near Rio de Janiero, Brazil.

Let us travel around South America with the young man and share with him, in his own words, his thoughts as he investigated the natural history of the area. He looked at everything — the plants, the animals, the insects, the people, the weather, the scenery, and especially the geology. It is fascinating to observe his realization of the vast extent of geologic time. This latter aspect is of extreme importance in his subsequent development of the theory of natural selection, for only with the availability of an almost unlimited amount of time in which to effect minute changes can this theory actually work.

For weeks the *Beagle* crossed the Atlantic Ocean, stopping only briefly at the Cape Verde Islands and at St. Paul's Rocks, where Darwin made most astute observations on this inconspicuous rockpile that is composed of deep oceanic material — pillow-basalts and serpentinite — in contrast to the normal volcanic island.

16th February 1832*

"This cluster of rocks . . . is 540 miles distant from the coast of America, and 350 from the island of Fernando Noronha. The highest point is only fifty feet above the level of the sea, and the entire circumference is under three-quarters of a mile. This small point rises abruptly out of the depths of the ocean. . . . It is a remarkable fact, that all the many small islands, lying far from any continent, in the Pacific, Indian, and Atlantic Oceans, with the exception of the Seychelles and this little point of rock, are, I believe, composed either of coral or of erupted matter. The volcanic nature of these oceanic islands is evidently an extension of that law, . . .

*This and succeeding quotations are taken verbatim from the "Journal of researches into the natural history and geology of the countries visited by H.M.S. Beagle" (Second Edition, 1845).

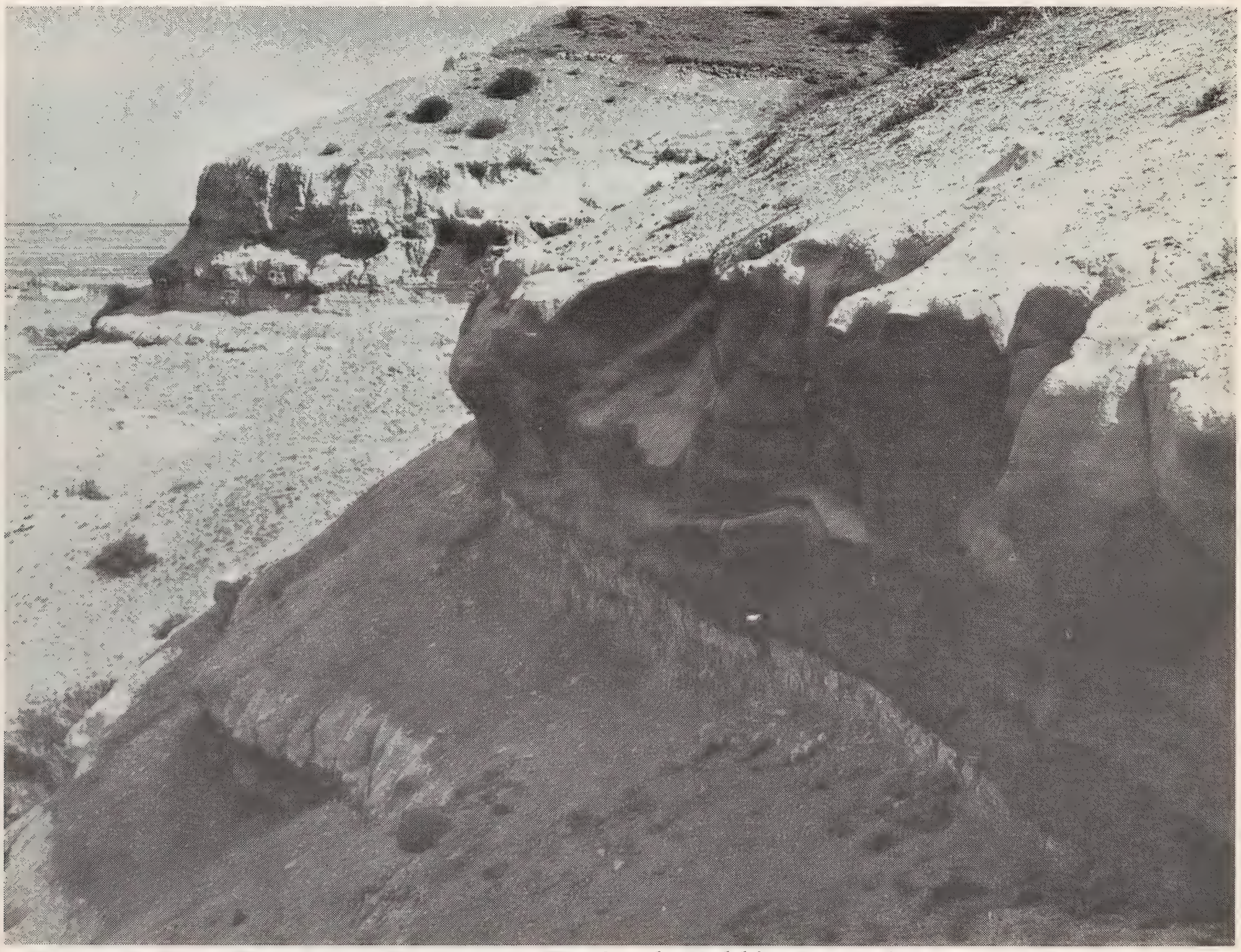

Figure 3. The "Pampean" Formation, Península Valdés, Argentina.

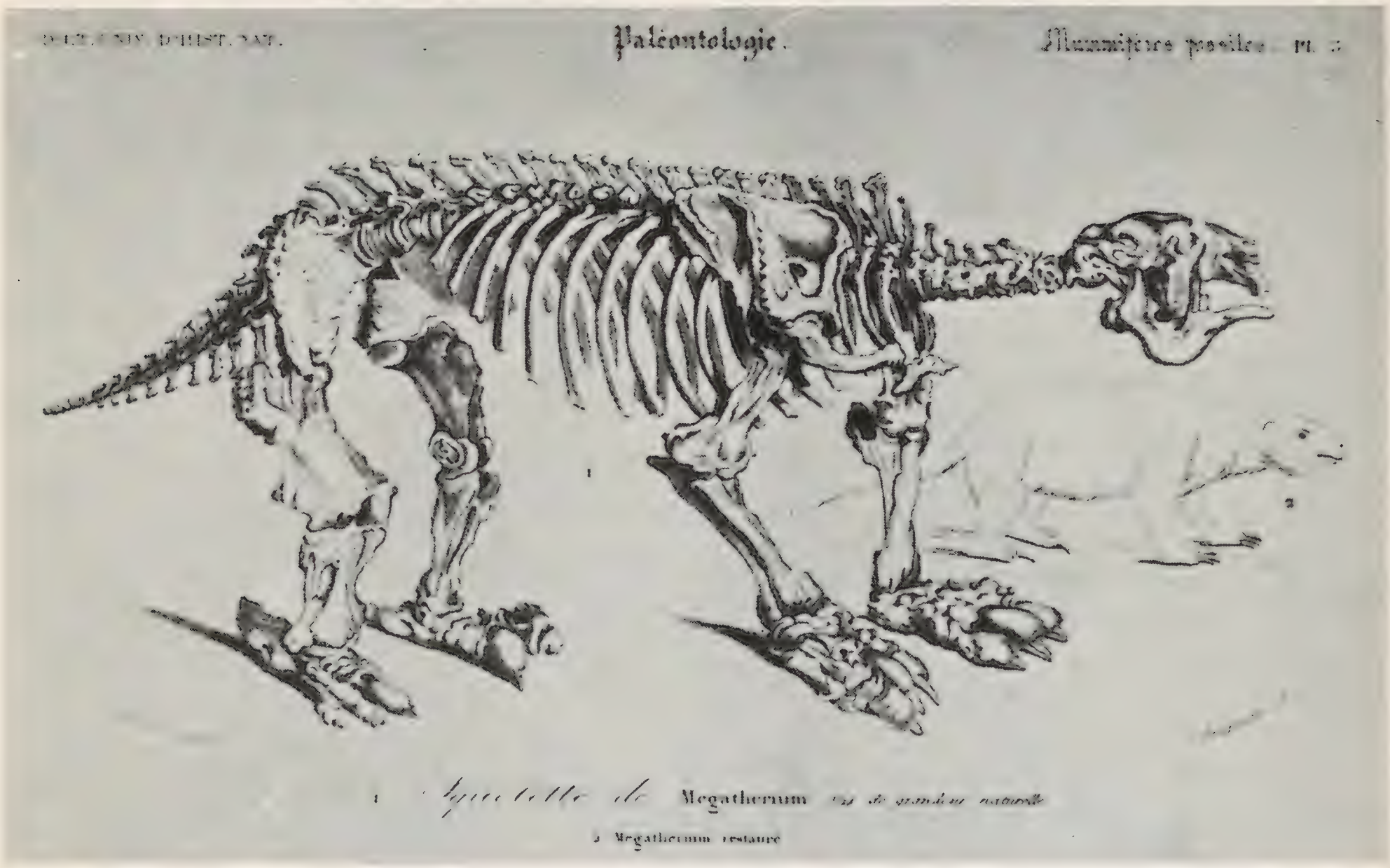

Figure 4. *Megatherium* — Dictionnaire Universel d'Histoire Naturelle.

Figure 5. *Glyptodon* in the La Plata Museum, Argentina.

from which it results that a vast majority of the volcanoes now in action stand either near sea-coasts or as islands in the midst of the sea."

Finally, nine weeks out of England, the *Beagle* arrived in Brazil. Darwin, who had been seasick for most of the time, immediately went on shore to recuperate and begin his studies. He writes in his diary:

29th February 1832

"It has been remarked, with much truth, that abruptly conical hills are characteristic of the formation which Humboldt designates as gneiss-granite. Nothing can be more striking than the effect of these huge rounded masses of naked rock rising out of the most luxuriant vegetation [fig. 1] . . . Along the whole coast of Brazil, for a length of at least 2000 miles, and certainly for a considerable space inland, wherever solid rock occurs, it belongs to a granitic formation. The circumstance of this enormous area being constituted of materials which most geologists believe to have been crystallized when heated under pressure, gives rise to many curious reflections. Was this effect produced beneath the depths of a profound ocean? or did a covering of strata formerly extend over it, which has since been removed? [fig. 2] Can we believe that any power, acting for a time short of infinity, could have denuded the granite over so many thousand square leagues."

On 24 August, 1833, the *Beagle* landed at Bahia Blanca, Argentina, and Darwin left the ship to make an overland trip to Buenos Aires, where he would meet it.

"The plain, at the distance of a few miles from the coast, belongs to the great Pampean formation [fig. 3], which consists in part of a reddish clay, and in part of a highly calcareous marly rock. . . . At Punta Alta we have a section . . . which is highly interesting from the number and extraordinary character of the remains of gigantic land animals embedded in it. . . . First, the *Megatherium,* [fig. 4] the huge dimensions of which are expressed by its name . . . [also] a large animal, with an osseous coat in compartments, very like that of an armadillo [fig. 5] . . . *Macrauchenia,* a huge beast with a long neck like a camel, . . . lastly the *Toxodon,* perhaps one of the strangest animals ever discovered: in size it equalled an elephant or megatherium, but the structure of its teeth, as Mr. Owen states, proves indisputably that it was intimately related to the Gnawers, the order which, at the present day, includes most of the smallest quadrupeds."

23rd December 1833

"We arrived at Port Desire, situated in latitude 47°, on the coast of Patagonia . . . The same evening I went on shore. The first landing in any new country is very interesting, and especially when, as in this case, the whole aspect bears the stamp of a marked and individual character. At the height of between two and three hundred feet . . . a wide plain extends, which is truly characteristic of Patagonia. The surface is quite level, and is composed of well-rounded shingle mixed with a whitish earth. Here and there scattered tufts of brown wiry grass are supported [fig. 6], and still more rarely, some low thorny bushes . . .

"The geology of Patagonia is interesting. Differently from Europe, where the tertiary formations appear to have accumulated in bays, here along hundreds of miles of coast we have one great deposit, including many tertiary shells, all apparently extinct. The most common shell is a massive gigantic oyster [fig. 7], sometimes even a foot in diameter. These beds are covered by others of a peculiar soft white stone, including much gypsum, and resembling chalk, but really of a pumiceous nature. It is highly remarkable, from being composed, to at least one-tenth part of its bulk, of Infusoria . . . at Port St. Julian its thickness is more than 800 feet! These white beds are everywhere capped by a mass of gravel, forming probably one of the largest beds of shingle in the world: it certainly extends from near the Rio Colorado to between 600 and 700 nautical miles

southward; at Santa Cruz (a river a little south of St. Julian), it reaches to the foot of the Cordillera; halfway up the river its thickness is more than 200 feet . . . We may consider its average breadth as 200 miles, and its average thickness about 50 feet. If this great bed of pebbles, without including the mud necessarily derived from their attrition, was piled into a mound, it would form a great mountain chain! . . . Yet all this gravel has been transported, and probably rounded, subsequently to the deposition of the white beds, and long subsequently to the underlying beds with the tertiary shells . . . The mind is stupified in thinking over the long, absolutely necessary, lapse of years.

"Everything in this southern continent has been effected on a grand scale: the land from the Rio Plata to Tierra del Fuego, a distance of 1200 miles, has been raised in mass within the period of the now-existing seashells . . . Nor has Patagonia been affected only by upward movements: the extinct tertiary shells from Port St. Julian and Santa Cruz cannot have lived, according to Professor E. Forbes, in a greater depth of water than from 40 to 250 feet; but they are now covered with sea-deposited strata from 800 to 1000 feet in thickness: hence the bed of the sea, on which these shells once lived must have sunk downwards several hundred feet, to allow the accumulation of the superincumbent strata. What a history of geological changes does the simply-constructed coast of Patagonia reveal!"

Darwin was an extremely astute geological observer but even he was a victim of his times, which did not admit to rivers cutting their own valleys, thus he erred in certain

Figure 6. Patagonian plain, near Península Valdés, Argentina.

Figure 7. Fossil oysters, near Comodoro Rivadavia, Argentina.

Figure 8. Rio Gallegos, southern Argentina.

Figure 9. Volcán Osorno (2661 meters), from Lago Todos Los Santos, Chile.

Figure 10. Cerro Aconcagua (7021 meters), from Paso de Bermejo, Argentina.

geological conclusions. For example, he recorded his thoughts on the formation of the valley of the Rio Santa Cruz, as he and the crew of the *Beagle* made a trip toward the headwaters of this Patagonian stream.

26th April 1834

"At the first glance of the basaltic cliffs on the opposite sides of the valley, it was evident that the strata once were united [fig. 8]. What power, then, has removed along a whole line of country a solid mass of very hard rock, which had an average thickness of nearly three hundred feet, and a breadth varying from rather less than two miles to four miles? The river, though it has so little power in transporting even inconsiderable fragments, yet in the lapse of ages might produce by its gradual erosion an effect, of which it is difficult to judge the amount. But in this case, . . . good reasons can be assigned for believing that this valley was formerly occupied by an arm of the sea. . . . If I had space I could prove that South America was formerly here cut off by a strait, joining the Atlantic and Pacific oceans, like that of Magellan. But it may yet be asked, how has the solid basalt been removed? Geologists formerly would have brought into play the violent action of some overwhelming *débâcle;* but in this case such a supposition would have been quite inadmissible; because, the same step-like plains with existing sea-shells lying on their surface, which front the long line of the Patagonian coast, sweep up on each side of the valley of Santa Cruz. No possible action of any flood could thus have modelled the land, either within the valley or along the open coast; and by the formation of such step-like plains or terraces the valley itself has been hollowed out. Although we know that there are tides, which run within the Narrows of the Strait of Magellan at the rate of eight knots an hour, yet we must confess that it makes the head almost giddy to reflect on the number of years, century after century, which the tides, unaided by a heavy surf, must have required to have corroded so vast an area and thickness of solid basaltic lava."

Darwin and the Beagle moved south, visiting Tierra del Fuego, then passing through the Straits of Magellan. At the island of Chiloe, from the town now known as Ancud, he observed the volcano Osorno, which is about 90 miles (airline) away.

26th November 1834

"The day rose splendidly clear. The volcano of Osorno [fig. 9] was spouting out volumes of smoke. This most beautiful mountain, formed like a perfect cone, and white with snow, stands out in front of the Cordillera . . .

"On the night of the 19th [January] the volcano of Osorno was in action. At midnight the sentry observed something like a large star, which gradually increased in size till about three o'clock, when it presented a very magnificent spectacle. By the aid of a glass, dark objects, in constant succession, were seen, in the midst of a great glare of red light, to be thrown up and to fall down. The light was sufficient to cast on the water a long bright reflection. . . . In the morning the volcano became tranquil.

"I was surprised at hearing afterwards that Aconcagua in Chile, 480 miles northwards, was in action on this same night; and still more surprised to hear, that the great eruption of Coseguina (2700 miles north of Aconcagua), accompanied by an earthquake felt over 1000 miles, also occurred within six hours of this same time. This coincidence is the more remarkable, as Coseguina had been dormant for twenty-six years: and Aconcagua most rarely shows any signs of action. It is difficult even to conjecture, whether this coincidence was accidental, or shows some subterranean connection. If Vesuvius, Etna, and Hecla in Iceland (all three relatively nearer each other, than the corresponding points in South America) suddenly burst forth in eruption on the same night, the coincidence would be thought remarkable; but it is far more remarkable in this case, where the three vents fall on the same great mountain-chain, and where the vast plains along the entire eastern coast, and the upraised recent shells along

Figure 11. The Andes as seen from near Chillan, Chile.

Figure 12. Paso de Bermejo, Chile-Argentina.

more than 2000 miles on the western coast, show in how equable and connected a manner the elevatory forces have acted."

The *Beagle* landed in Valparaiso, the chief port of Chile. Darwin was ecstatic.

23rd July 1834

"When morning came everything appeared quite delightful. After Tierra del Fuego the climate felt quite delicious — the atmosphere so dry, and the heavens so clear and blue with the sun shining brightly, that all nature seemed sparkling with life . . .

"The volcano of Aconcagua [fig. 10] is particularly magnificent. This huge and irregularly conical mass has an elevation greater than that of Chimborazo; for, from measurements made by the officers in the *Beagle*, its height is no less than 23,000 feet. The Cordillera, however, viewed from this point, owe the greater part of their beauty to the atmosphere through which they are seen. When the sun was setting in the Pacific, it was admirable to watch how clearly their rugged outlines could be distinguished, yet how varied and how delicate were the shades of their colour.

"The appearance of the Andes was different from that which I had expected. The lower line of the snow was of course horizontal, and to this line the even summits of the range seemed quite parallel. Only at long intervals, a group of points or a single cone, showed where a volcano had existed or does now exist. Hence the range resembled a great solid wall [fig. 11], surmounted here and there by a tower,

Figure 13. Andes near Portillo, Chile.

and making a most perfect barrier to the country . . .

"Two days afterwards I set out to cross the Cordillera . . . In this part of Chile there are two passes across the Andes to Mendoza: the one most commonly used — namely that of Aconcagua or Uspallata — is located some way to the north; the other, called the Portillo, is to the south, and nearer, but more lofty and dangerous . . . We set out for the Portillo pass . . .

"In this part of the valley, the mountains on each side were from 3000 to 6000 or 8000 feet high, with rounded outlines and steep bare flanks. The general colour of the rock was dullish purple, and the stratification very distinct. If the scenery was not beautiful, it was remarkable and grand . . .

"The lofty mountains, their summits marked with a few patches of snow, stood well separated from each other; the valleys being filled up with an immense thickness of stratified alluvium [fig. 12]. The features in the scenery of the Andes which struck me most, were . . . the smooth conical piles of fine and brightly-coloured detritus [fig. 13], which sloped up at a high angle from the base of the mountains, sometimes to a height of more than 2000 feet.

"I frequently observed, both in Tierra del Fuego and within the Andes, that where the rock was covered during the greater part of the year with snow, it was shivered in a very extraordinary manner into small angular fragments.

"The road, which as yet had been good with a steady but very gradual ascent, now changed into a steep zigzag track up the great range [fig. 14], dividing the republics of Chile and

Figure 14. Highway from Santiago, Chile, to Mendoza, Argentina.

Figure 15. Trigoniidae de Chile: Reyes and Perez, 1979, Revista Geológico de Chile, no. 8, pl. 2.

Figure 16. Andes near Portillo, Chile.

[Argentina] . . . About noon we began the tedious ascent of the Peuquenes ridge, and then for the first time experienced some little difficulty in our respiration . . . The short breathing from the rarified atmosphere is called by the Chilenos 'puna;' . . . the only sensation I experienced was a slight tightness across the head and chest . . . There was some imagination even in this; for upon finding fossil shells [fig. 15] on the highest ridge, I entirely forgot the puna in my delight . . . The inhabitants all recommend onions for the puna; as this vegatable has sometimes been given in Europe for pectoral complaints, it may possibly be of real service: — for my part I found nothing so good as the fossil shells!"

Darwin gives a brief account of the geology of the Cordillera, concluding:

"The shells in the Peuquenes or oldest ridge, prove . . . that it has been upraised 14,000 feet since a Secondary period [fig. 16], which in Europe we are accustomed to consider as far from ancient; but since these shells lived in a moderately deep sea, it can be shown that the area now occupied by the Cordillera, must have subsided several thousand feet — in northern Chile as much as 6000 feet — so as to have allowed that amount of submarine strata to have been heaped on the bed on which the shells lived . . . Daily it is forced home on the mind of the geologist, that nothing, not even the wind that blows, is so unstable as the level of the crust of this earth."

The truth of this statement was most forcefully brought home to Darwin the following year, when he was ashore at Valdivia and experienced a severe earthquake.

20th February 1835

"A bad earthquake at once destroys our oldest associations: the earth, the very emblem of solidity, has moved beneath our feet like a thin crust over a fluid;—one second of time has created in the mind a strange idea of insecurity, which hours of reflection would not have produced."

The *Beagle* arrived at Concepcion, some 200 miles to the north, to learn that the same earthquake had totally devastated the area.

4th March 1835

"The next day I landed at Talcahuano, and afterwards rode to Concepcion. Both towns presented the most awful yet interesting spectacle I ever beheld . . . In Concepcion each house or row of houses stood by itself, a heap or a line of ruins . . . It is generally thought that this is the worst earthquake ever recorded in Chile; but . . . this cannot easily be known; nor indeed would a much worse shock have made any great difference, for the ruin was now complete.

"The town of Concepcion was built in the usual Spanish fashion, with all the streets running at right angles to each other; one set ranging S.W. by W., and the other set N.W. by N. The walls in the former direction certainly stood better than those in the latter . . . The different resistance offered by the walls, according to their direction was well exemplified in the case of the Cathedral [fig. 17]. The side which fronted the N.E. presented a great pile of ruins . . . the side walls . . . though exceedingly fractured, yet remained standing; but the vast buttresses (at right angles to them, and therefore parallel to the walls that fell) were in many cases cut clean off, as if by a chisel."

In particular he noted the means by which the gradual uplift of the Andes had been achieved.

"The most remarkable effect of this earthquake was the permanent elevation of the land; it would probably be far more correct to speak of it as the cause. There can be no doubt that the land round the Bay of Concepcion was upraised two or three feet; . . . At the island of S. Maria (about thirty miles distant) the elevation was greater; on one part, Captain Fitz Roy found beds of putrid mussel-shells *still adhering to the rocks*, ten feet above high-water mark: the inhabitants had formerly dived at low-water spring-tides for these shells. The elevation of this

province is particularly interesting, from its having been the theatre of several other violent earthquakes, and from the vast numbers of sea-shells scattered over the land, up to a height of certainly 600, and I believe, of 1000 feet. At Valparaiso, as I have remarked, similar shells are found at the height of 1300 feet: it is hardly possible to doubt that this great elevation has been effected by successive small uprisings, such as that which accompanied or caused the earthquake of this year, and likewise by an insensibly slow rise, which is certainly in progress on some parts of this coast . . .

"From the intimate and complicated manner in which the elevatory and eruptive forces were shown to be connected during this train of phenomena, we may confidently come to the conclusion, that the forces which slowly and by little starts uplift continents, and those which at successive periods pour forth volcanic matter from open orifices, are identical. From many reasons, I believe that the frequent quakings of the earth on this line of coast, are caused by the rending of the strata, necessarily consequent on the tension of the land when upraised, and their injection by fluidified rock. This rending and injection would, if repeated often enough (and we know that earthquakes repeatedly affect the same areas in the same manner), form a chain of hills; and the linear island of St Mary, which was upraised thrice the height of the neighbouring country, seems to be undergoing this process. I believe that the solid axis of a mountain, differs in its manner of formation from a volcanic hill, only in the molten stone having been repeatedly injected, instead of having been repeatedly ejected. Moreover, I believe that it is impossible to explain the structure of great mountain-chains, such as that of the Cordillera, where the strata, capping the injected axis of plutonic rock, have been thrown on their edges along several parallel and neighbouring lines

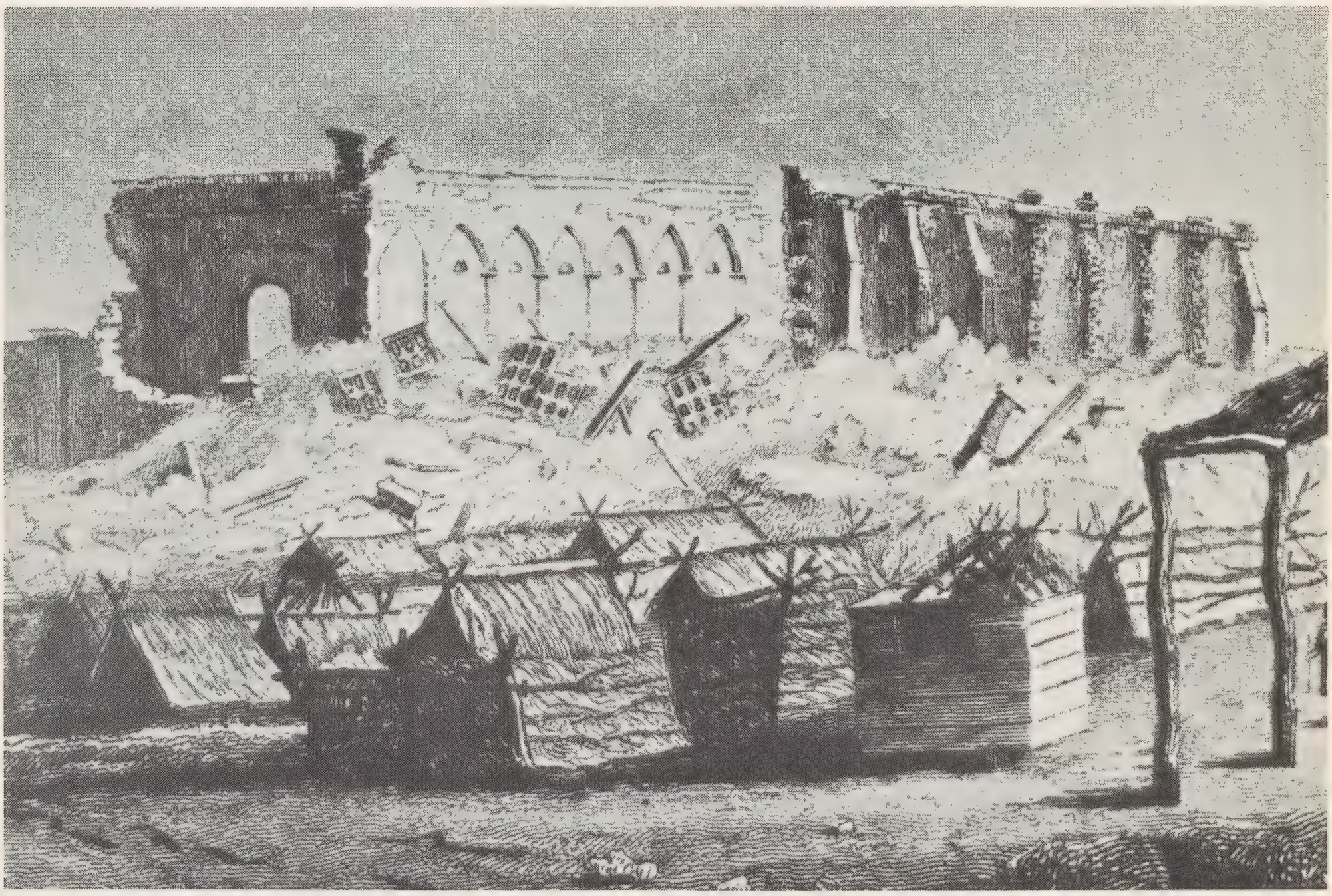

Figure 17. Sketch of Cathedral in Concepcion, made by J. C. Wickham, from *Narrative of the surveying voyages of HMS Adventure and Beagle*.

Figure 18. Cliffs at Navidad, Chile.

Figure 19. Fossiliferous sandstone at Navidad, Chile.

of elevation, except on this view of the rock of the axis having been repeatedly injected, after intervals sufficiently long to allow the upper parts or wedges to cool and become solid."

During August and September Darwin took a "geologising" excursion out of Valparaiso.

"We followed this valley till it expanded into a great plain, which reaches from the sea to the mountains west of Rancagua. We shortly lost all trees and even bushes; so that the inhabitants are nearly as badly off for firewood as those in the Pampas . . . The next day we arrived at a house near Navedad, on the seacoast, where a rich Haciendero gave us lodgings. I stayed here the two ensuing days, and although very unwell, managed to collect from the tertiary formation some marine shells."

Darwin may have been unwell but he managed to observe the following:

"The cliffs here are about 800 feet in height [fig. 18]; they consist, wherever I could examine them, of fine grained, yellowish, earthy sandstones, with ferrugineous veins, and with concretions of hard calcareous sandstone [fig. 19] . . . The sandstone contains fragments of wood, either in the state of lignite or partly silicified, sharks' teeth, and shells in great abundance, both high up and low down the sea-cliffs. *Pectunculus* and *Oliva* were most numerous in individuals, and next to them *Turritella* and *Fusus*. I collected in a short time, though suffering from illness, 31 species [fig. 20], all of which are extinct, and several of the genera do not now range nearly so far south.*"

From Valparaiso Darwin also made an excursion into the Atacama desert of northern Chile. He traveled to Copiqpó, 420 miles to the north, where he was picked up once

*This passage is from "Geological Observations."

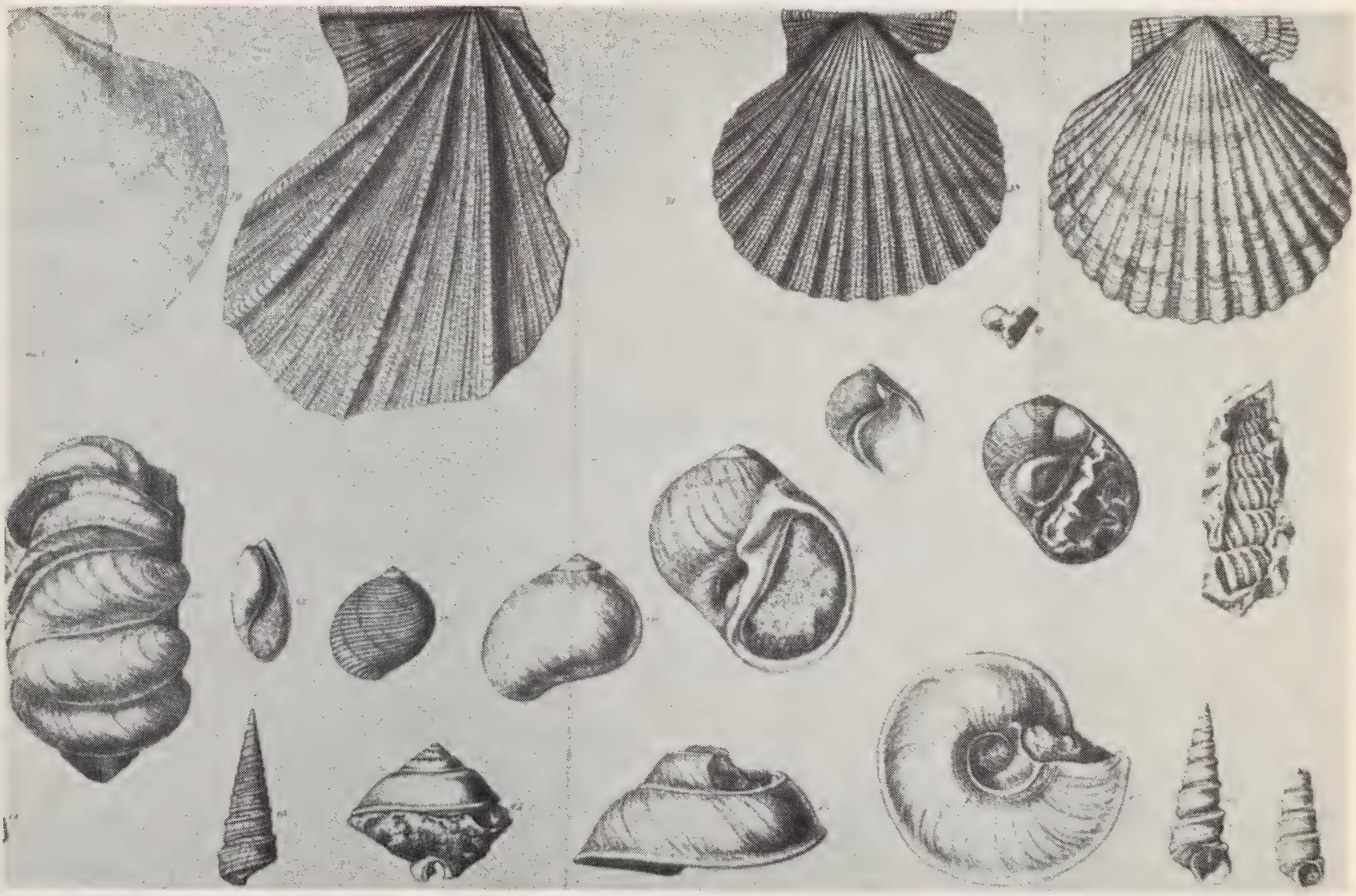

Figure 20. Tertiary fossil shells from South America. Plate 3, *Geological Observations* (1846).

Figure 21. The Atacama Desert, near Antofagasta, Chile.

Figure 22. Train station at Cere, near Chuquicamata, Chile.

again by the *Beagle*. Due to seasickness Darwin traveled by land as much as possible.

> "During each day's ride further northward, the vegetation became more and more scanty . . . I am tired of repeating the epithets barren and sterile [fig. 21]. These words, however, as commonly used are comparative; I have always applied them to the plains of Patagonia, which can boast of spiny bushes and some tufts of grass; and this is absolute fertility, as compared with northern Chile.
>
> "The appearance of the country was remarkable, from being covered by a thick crust of common salt, and of a stratified saliferous alluvium . . . The existence of this crust . . . shows how extraordinarily dry the climate must have been for a long period."

However it does occasionally rain even in the Atacama, and when it does the effects are disastrous.

> "After two or three very dry years . . . a rainy year generally follows; and this does more harm than even the drougth. The rivers swell, and cover with gravel and sand the narrow strips of ground, which alone are fit for cultivation . . . Great devastation has thus been caused three years ago" [fig. 22].

From Copiapó Darwin sailed to Lima, about which he had very little good to say. From here the *Beagle* turned westward, next putting in the Galápagos Islands. It was here, as we all know, he first began the musings upon species differentiation that would ultimately lead to his theory of evolution. However, at the time, his sole observation on the finches was limited to a short paragraph.

> "The most curious fact is the perfect gradation in the size of the beaks in the different species of *Geospiza* . . . Seeing this gradation and diversity of structure in one small, intimately related group of birds, one might really fancy that from an original paucity of birds in this archipelago, one species had been taken and modified for different ends."

From the Galápagos Islands the *Beagle* headed across the Pacific Ocean, stopping at Tahiti, New Zealand, and Australia, but spending only a little time at each place. His geological interest was not excited again until the ship arrived at the Cocos-Keeling Islands in the Indian Ocean. Here he discovered the wonders of the coral atoll and formulated his theory of atoll formation, which, had it not been subsequently so totally overshadowed by his biological achievements, alone would have earned him a permanent place among the ranks of the great geologists.

12th April 1836

> "I am glad we have visited these islands; such formations surely rank high amongst the wonderful objects of this world. Captain Fitz Roy found no bottom with a line 7200 feet in length, at the distance of only 2200 yards from the shore; hence this island forms a lofty submarine mountain, with sides steeper even than those of the most abrupt volcanic cone. The saucer-shaped summit is nearly ten miles across; and every single atom, from the least particle to the largest fragment of rock, in this great pile, which however is small compared with very many other lagoon-islands, bears the stamp of having been subjected to organic arrangement. We feel surprise when travellers tell us of the vast dimensions of the Pyramids and other great ruins, but how utterly insignificant are the greatest of these, when compared to these mountains of stone accumulated by the agency of various minute and tender animals! This is a wonder which does not at first strike the eye of the body, but, after reflection, the eye of reason."

The effects of this trip upon Darwin were manifold, not the least of which was his discovery of the wonders of geology. While a student at the University of Edinburgh he had found lectures in geology by Jameson "incredibly dull" and he left the University with the determination "never as long as I lived to read a book on geology or in any way study the science." Only five years later, in South America he raved:

> "Geology carries the day. I find in geology a never failing interest, it creates the same grand ideas respecting this world which astronomy does for the universe."

A reflection of this can be seen in the fact that, as Sir Gavin de Beer noted in his Introduction to the 1957 Edition of the "Journal of Researches," there is a title change between the first and second editions of this work, indicating that his initial enthusiasm was geological and only after long retrospection was it replaced by Biology. The first edition (1839) carries the subtitle "into the geology and natural history. . ." but the second edition (1845) reads: "into the natural history and geology. . ." It is also made obvious when one reads the last pages of the Journal, as Darwin takes a retrospective look over what he termed "the advantages and disadvantages, the pains and pleasures, of our circumnavigation of the world."

> "In calling up images of the past, I find that the plains of Patagonia frequently pass cross before my eyes; [fig. 23] yet these plains are pronounced by all wretched and useless. They can be described only by negative characters; without habitations, without water, without trees, without mountains, they support merely a few dwarf plants. Why, then, and the case is not peculiar to myself, have these arid wastes taken so firm a hold on my memory? . . . I can scarcely analyse these feelings; but it must be partly owing to the free scope given to the imagination. The plains of Patagonia are boundless; . . . they bear the stamp of having lasted, as they are now, for ages, and there appears no limit to their duration through future time."

Darwin had become a geologist.

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This paper is the result of a trip around South America, made possible by an invitation to teach one semester at the Universidade Federale do Rio Grande do Sul, Porto Alegre, Brazil. This kind invitation was made by Darcy Closs, then Director of the Department of Paleontology at that institution. and mere words cannot express our gratitude to him for having provided us with such a marvelous experience. After leaving Porto Alegre, we were additionally helped by Jose Stuardo, then at the University of Concepcion, Chile, whose gracious hospitality included not only living accommodations, the loan of Maria Villaroel (then a graduate student) as a guide to Darwin's fossil localities, but included, above and beyond the call of duty, meeting a train that arrived several hours late at the unholy hour of 3 a.m. Not since Robinson Crusoe discovered Friday, has the sight of another human being been so welcome (we arrived in Chile the day Nixon declared the U. S. was off the gold standard and no banks would accept U. S. traveler's checks!).

To all these people, as well as an array of nameless people such as taxi drivers, who helped us find strange places where we might collect fossils and who then helped us collect the fossils, train clerks who took a chance on U. S. funds, little old ladies who fed us strange and wonderful food, museum guards who opened the La Plata Museum on Sunday so that we might photograph the skeletons, and many others who remain only a warm glow in our memory, we say — Muchísimas gracias!

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Figure 23. Wildflowers in the Patagonian Spring, near Comodoro Rivadavia, Argentina.

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BIOSTRATIGRAPHY AND PALEOECOLOGY OF LOWER PALEOZOIC, UPPER CRETACEOUS, AND LOWER TERTIARY ROCKS IN U.S. GEOLOGICAL SURVEY NEW MADRID TEST WELLS, SOUTHEASTERN MISSOURI

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UNITED STATES GEOLOGICAL SURVEY

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I. ABSTRACT

The paleontology and biostratigraphy of Tertiary, Cretaceous, and Paleozoic rocks in the upper Mississippi embayment are incompletely known because marine fossils are only locally present in these rocks. This study concerns material from two U.S. Geological Survey test wells drilled in New Madrid County, southeastern Missouri, as part of earthquake hazard studies in the northern Mississippi Embayment.

Test well 1 sampled lower Tertiary strata to a depth of 146 ft; these strata were found to be late Eocene in age on the basis of sporomorphs. Test well 1-X, 29 ft northwest of well 1, provided cuttings and cores from lower Tertiary, Upper Cretaceous, and lower Paleozoic rocks to a total depth of 2,316 ft below the Kelly bushing (at an altitude of 288 ft). Lithologic evidence suggests that the base of the Jackson Formation may be at 270 ft, but sporomorphs indicate that the base of the Jacksonian Stage (upper Eocene) is possibly at a depth of about 350 ft in test well 1-X. Lithologic units of the Claibornian Stage (middle Eocene) here consist of the Cockfield(?) and Cook Mountain(?) Formations and Memphis Sand, in descending order. The Claibornian could not be subdivided using sporomorphs from cuttings, but sporomorphs show that the top of the Sabinian Stage (top of the lower Eocene) is at about 1,055 ft; lithologically, the top of the Wilcox Group (top of the Flour Island Formation) is at

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1,048 ft. Sporomorphs suggest that the top of the lower Sabinian (top of the Paleocene) is within the Flour Island Formation at about 1,105 ft. The next major lithologic break, the top of the Fort Pillow Sand at 1,186 ft, does not coincide with any detectable biostratigraphic boundary. Lithologically, the interval from 1,339 to 1,377 ft may belong to the Old Breastworks Formation; dinoflagellates from cuttings indicate that this interval is likely to be late Midwayan in age and, therefore, correlative with the Naheola Formation of the eastern Gulf Coast. The Porters Creek Clay extends from a probable top at 1,377 ft to 1,691 ft, and the base of the underlying Clayton Formation (Tertiary-Cretaceous contact) is at 1,703 ft. Calcareous nannofossils, dinoflagellates, foraminifers, mollusks, ostracodes, and sporomorphs from continuous cores of the Porters Creek Clay and Clayton Formation indicate that the upper half of the Porters Creek correlates with the upper part of the same formation or perhaps partly with slightly younger rocks in the eastern Gulf Coast, the lowermost Porters Creek appears to correlate with the upper part of the Clayton Formation of the eastern Gulf Coast and with the Kincaid Formation of Texas, and the thin Clayton of the test well probably correlates with only the lower part of the thicker Clayton of the eastern Gulf Coast. Sporomorphs from McNairy Sand (Upper Cretaceous) cores indicate Maestrichtian and perhaps latest Campanian Age. Lower Paleozoic dolostone from 2,023 ft to total depth at 2,316 ft is barren of identifiable fossils except for a probable fragment of the fish *Anatolepis;* the dolostone is probably Late Cambrian in age.

The McNairy Sand of New Madrid well 1-X seems to have been deposited in nonmarine to nearshore marine environments; the Clayton Formation and lower part of the Porters Creek Clay were deposited under marine conditions during an early Paleocene marine transgression. A major regression followed that continued through the end of Porters Creek time and perhaps into Naheola (late Midwayan) time; the Sabinian, Claibornian, and Jacksonian strata in southeastern Missouri were deposited primarily or entirely in nonmarine environments.

II. INTRODUCTION

The paleontology and biostratigraphy of Tertiary, Cretaceous, and Paleozoic rocks in the northern Mississippi Embayment are incompletely known because marine fossils are only locally present in these rocks. Many of the lower Tertiary and Cretaceous rocks were deposited in nonmarine environments, and some marine units lack calcareous fossils because of leaching (Lamar and Sutton, 1930; Shourd and Winter, 1980). The Paleozoic carbonate rocks are commonly coarsely crystalline, dolomitic, and only sparsely fossiliferous. Many papers have been written on the taxonomy of sporomorphs (spores and pollen grains) from the lower Tertiary and Cretaceous of the northern Mississippi Embayment, but much remains to be learned about the sporomorph biostratigraphy of these rocks. No papers have been published on the taxonomy or biostratigraphy of fossil dinoflagellates in this region.

In this study, we examined Tertiary and Cretaceous rocks for calcareous nannofossils (Bybell, Smith), dinoflagellates (Edwards), foraminifers (Gibson), mollusks (Ward), ostracodes (Hazel), and sporomorphs (Christopher, Frederiksen) and Paleozoic rocks for conodonts and vertebrate remains (Repetski). The lithostratigraphy is by Crone and Russ.

The material studied is from U.S. Geological Survey New Madrid test wells 1 and 1-X, drilled in the autumn of 1978 as part of the Survey's Earthquake Hazards Reduction Program. One of the prime goals of the wells was to obtain data about the active tectonic stress field from *in situ* hydrofracture stress measurements in the subsurface Paleozoic rocks. A second objective was to obtain good quality samples and modern geophysical logs of the stratigraphic section in the New Madrid area. The stratigraphy and structure of this part of the Embayment are poorly known because few deep wells and test holes have been drilled. Finally, as mentioned previously, relatively little is known about the biostratigraphy particularly of micro- and nannofossils in the northern Mississippi Embayment; sampling of the test wells provided an excellent opportunity to study a

variety of fossils from the post-Paleozoic rocks of the New Madrid area, to correlate these rocks with much better known sections elsewhere in the Gulf Coast, and to compare the generally nonmarine to nearshore marine facies of the northern Mississippi Embayment with the more marine litho- and biofacies of the Gulf Coast.

New Madrid test wells 1 and 1-X are located in SW ¼ SW ¼ SE ¼ sec. 32, T. 21 N., R. 14 E., U.S.G.S. Point Pleasant 7½ minute quadrangle, New Madrid County, Mo., just west of Missouri State Highway 162 (fig. 1). Test well 1 is 323 ft (98.5 m) N. 40° W. of U.S.G.S. benchmark 283, and test well 1-X is 29 ft (8.9 m) northwest of well 1. Sample depths are measured below the Kelly bushing, which was at an altitude of 288 ft. (Measurements in this paper are cited in English units to maintain consistency with standard drilling usage). Small discrepancies of several feet are evident between depths marked on cutting bags and core boxes and depths recorded on the geophysical logs. In this paper, depths of fossil samples are those marked on the bags and boxes whereas depths of lithostratigraphic unit tops and bases are from the geophysical logs (see fig. 2), which are more accurate.

Preliminary reports on the drilling history and stratigraphy of test well 1-X were prepared by Crone and Russ (1979) and Russ and Crone (1979), and a detailed description of the samples from well 1-X is provided by Crone (1981). Test well 1 was drilled to a total depth of 237 ft and casing was set at 146 ft. Cuttings suggested that, below the Quaternary alluvium, the top of the lower Tertiary gray clay was at about 125-130 ft. The interval from 205-237 ft was cored, but the core barrel repeatedly snagged on the bottom of the casing as it was being retrieved. The casing had to be pulled, and the core from 205 to 237 ft was lost. Fortunately, a thick mass of lower Tertiary mudstone exhibiting well preserved stratification was lodged in the bottom of the casing; this mass represents a "core" within the interval between about 125 ft (the top of the preserved lower Tertiary) and 146 ft (the lower end of the casing).

The rig was moved, and drilling commenced for test well 1-X. This well was initially drilled to 142 ft; cuttings indicated the top of the lower Tertiary was at approximately 135 ft. Surface casing was set and cemented to 140 ft. The well was then drilled to 1,388 ft, near the top of the Porters Creek Clay (lower Paleocene); cuttings were collected at five-foot intervals from 140 to 1,388 ft. After the well was logged, eight sidewall cores were collected between 255 and 500 ft. The well was deepened to 1,400 ft, and a string of casing was set and cemented to that depth. Below the casing, continuous coring recovered nearly a complete section of the Porters Creek Clay between 1,415 and 1,691 ft and much of the Clayton Formation from 1,691 to 1,703 ft (1,696 to 1,704.5 ft according to the core boxes). In the Upper Cretaceous section from 1,703 ft to the top of the lower Paleozoic dolostone at 2,023 ft, only seven 1- to 10-ft intervals of clay, silt, and sand were recovered by coring, but samples of cuttings were collected at five-foot intervals. The Paleozoic dolostone was cored from 2,023 to 2,028 ft with minimal recovery, but cuttings were collected from 2,028 ft to total depth at 2,316 ft.

Figure 1. Location of the New Madrid and Fort Pillow test wells.

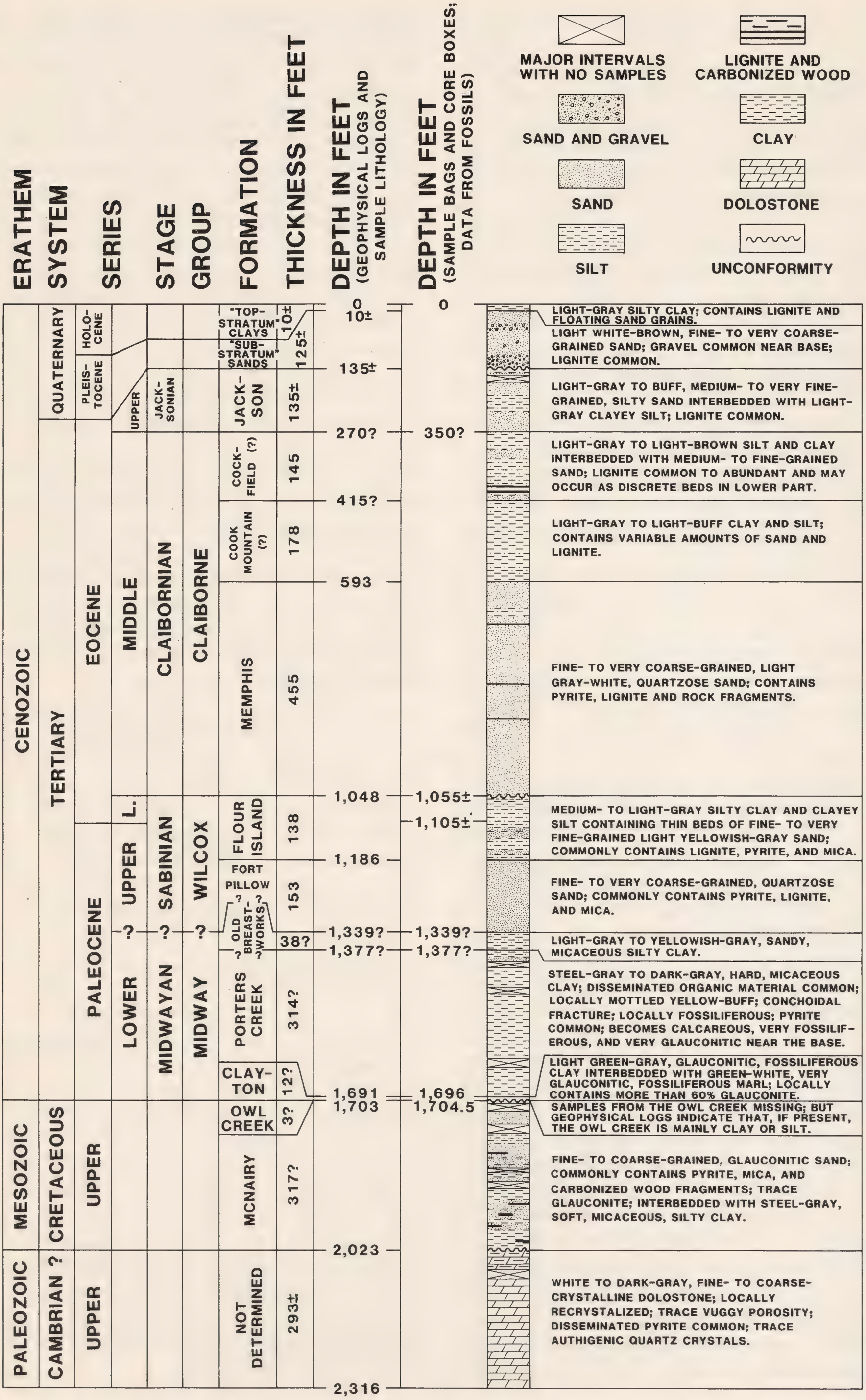

Figure 2. Diagram of rock and time-rock units below the Mississippi Valley alluvium in New Madrid test wells 1 and 1-X.

III. BIOSTRATIGRAPHY

Eocene and Paleocene

Useful samples available from the upper part of the Tertiary section in the test wells consist of the "core" (casing) sample from 125-146 ft in well 1 and sidewall core samples from 350, 395, and 500 ft in well 1-X. The sidewall core samples from 255, 270, 410, and 470 ft are barren or nearly barren of palynomorphs, and the sidewall core sample from 485 ft was not examined. Cuttings from the upper and middle Eocene of the test wells are difficult to use for sporomorph age determinations because they are heavily contaminated with cavings of upper Eocene material, and at the same time many of the samples contain reworked material of early Eocene to Cretaceous age.

Sixty sporomorph taxa have been identified in core samples from strata of the upper Eocene and the upper part of the middle Eocene in New Madrid wells 1 and 1-X (Table 1). However, the precise position of the upper Eocene-middle Eocene boundary in the Gulf Coast is not easily determined by sporomorphs. Many late Eocene sporomorph species are different from those of the middle part of the middle Eocene (Tschudy, 1973a; Elsik, 1974), but sporomorph assemblages of the upper Eocene are nearly identical to those in the uppermost part of the middle Eocene (Frederiksen, 1980a).

The "core" sample from 125-146 ft (Table 1) contains a rich sporomorph assemblage typical of the upper Eocene and the uppermost middle Eocene. The presence of *Momipites annulatus* indicates that the sample is not older than late Eocene. The cuttings sample from 305-310 ft of test well 1-X probably includes cavings; this sample contains *Parsonsidites conspicuus* Frederiksen 1973, which is only known from the upper Eocene and lower Oligocene. The youngest early Tertiary rocks exposed on the surface in southeastern Missouri are assigned to the Holly Springs Sand or Formation (Koenig, 1961), which is thought to be middle to early Eocene in age (references in Keroher and others, 1966, p. 1784-1785). However, the Jackson Formation was tentatively identified in the Fort Pillow test well 55 mi to the south-southwest of the New Madrid wells, in Lauderdale County, Tenn. (fig. 1; Moore and Brown, 1969), and the Jacksonian Stage has been identified on the basis of sporomorphs in southwestern Kentucky (by R.H. Tschudy; see Olive, 1980). This paper confirms that the Jacksonian Stage also occurs in the subsurface of southeastern Missouri.

The sidewall core sample from 350 ft could be from either the upper Eocene or the upper part of the middle Eocene, and we tentatively place the biostratigraphic boundary between the upper and middle Eocene (= the Jacksonian-Claibornian Provincial Stage boundary) at this level (fig. 2). Lithologically, the Jackson and Cockfield Formations are difficult to distinguish from one another; however, geophysical log correlations suggest that the formation contact might be at 270 ft. The sidewall core sample from 395 ft is probably late middle Eocene in age based on the occurrence of a fair number of specimens of *Gothanipollis* and aff. *Symplocospollenites* of Tschudy (1973a) and the presence of *Hippocrateaceaedites*. On the Gulf Coast, *Gothanipollis* is found mainly in the middle Eocene and is only sparsely represented in the upper Eocene; the form of *Symplocospollenites* in the sample from 395 ft is similar to one found only in the middle Eocene to Paleocene of the Gulf Coast by Tschudy (1973a); *Hippocrateaceaedites* has previously been found in North America only in the middle Eocene of California (Frederiksen, unpublished data). The first downhole appearance of *Gothanipollis* in the cuttings is at 445-450 ft; this sample also has the first probable *Alangiopollis*. Like *Gothanipollis*, *Alangiopollis* is mainly a middle Eocene genus on the Gulf Coast; *Alangiopollis* is very rare in the upper Eocene of that region. The sidewall core from 500 ft seems clearly to be from the upper part of the middle Eocene because *Celtis* and *Gothanipollis* are fairly abundant in this sample, which also contains probable *Alangiopollis*. *Platycarya* pollen may range to near the top of the middle Eocene on the Gulf Coast, but it is rare above the lower part of the middle Eocene. The specimen of *Platycarya* found in the sample from 500 ft may be reworked; several taxa of reworked lower Eocene to Cretaceous sporomorphs occur in this sample. Several specimens of *Graminidites* (grass family) were also found in the sample from 500 ft. This pollen form probably does not range far below the top of the middle Eocene on the Gulf Coast. The possibility cannot be excluded that the grass pollen grains in the sample could be modern con-

taminants. However, the only occurrence of grass pollen in the cuttings was at 490-495 ft; similar contamination of two samples collected and processed separately seems unlikely. The gradual change in the sporomorph assemblages from 125-146 to 500 ft suggests more or less continuous deposition across the upper Eocene-middle Eocene boundary in the area of the test well.

Dinoflagellates were examined from the "core" sample from 125-146 ft, and the following taxa were found:

Chatangiella sp.
Fibrocysta bipolare (Cookson & Eisenack, 1965) Stover & Evitt, 1978
Isabelidinium acuminata (Cookson & Eisenack, 1958) Stover & Evitt, 1978
Odontochitina costata Alberti, 1961
Callaiosphaeridium asymmetricum (Deflandre & Courteville, 1939) Davey & Williams, 1966

The specimens seem to be quite oxidized and represent a reworked Cretaceous assemblage. The known range of *O. costata* is from Campanian to Cenomanian; the assemblage seems to be late but not latest Cretaceous in age.

On the basis of lithologic correlation between New Madrid well 1-X and the Fort Pillow test well (Moore and Brown, 1969; Crone, 1981), the Claiborne Group in the New Madrid well is tentatively divided, in descending order, into the Cockfield Formation, Cook Mountain Formation, and Memphis Sand (fig. 2). However, the Claiborne Group could not be subdivided biostratigraphically on the basis of sporomorphs from the cuttings. Undescribed species were seen that are probably middle Eocene in age, but the relatively few marker species and genera for the middle Eocene listed by Tschudy (1973a) and Elsik (1974) were not found.

Reworked lower Eocene and Paleocene sporomorphs are consistently present in the upper and middle Eocene samples, but the reworked material is only a small percentage of total sporomorphs. At 1,055-1,060 ft, the cuttings sample contains quite a few specimens of *Platycarya platycaryoides*. This species is rare above the lowermost part of the middle Eocene and has its peak occurrences in the lower Eocene; therefore, we take the top of the lower Eocene as being at about 1,055 ft.

Lithologically, the contact between the Memphis Sand (lower part of the Claiborne Group) and the underlying Flour Island Formation (upper part of the Wilcox Group) in the New Madrid well is placed at 1,048 ft. In the Fort Pillow well in Tennessee, the lower part of the Memphis Sand contained sporomorphs typical of the lower part of the Claiborne Group (middle Eocene), whereas the upper part of the Flour Island Formation had sporomorphs found in the Wilcox Group (lower Eocene to upper Paleocene; R.H. Tschudy, *in* Moore and Brown, 1969).

Table 1. Sporomorphs in cores from the upper Eocene and upper part of the middle Eocene, New Madrid test wells 1 and 1-X. Depth in ft.

	Test well 1	Test well 1-X		
	125-145	350	395	500
Chrysophyllum brevisulcatum (Frederiksen, 1973) Frederiksen, 1980	X			
Ephedra hungarica (Nagy, 1963) Frederiksen, 1980	X			
Juglans nigripites Wodehouse, 1933	X			
Lymingtonia cf. *L. rhetor* Erdtman, 1960	X			
Planera? thompsoniana Traverse, 1955	X			
Tilia instructa (Potonie, 1931) Frederiksen, 1980	X			
Triatriopollenites sp. (*Comptonia* type)	X			
Ilex spp.	X	X		
Intratriporopollenites stavensis Frederiksen, 1980	X	X		
Liliacidites tritus Frederiksen, 1973	X	X		
Platanus sp.	X	X		
Quercoidites microhenricii (Potonie, 1931) Potonie, 1960	X	X		
Symplocos contracta Frederiksen, 1980	X	X		
Ailanthipites berryi Wodehouse, 1933	X	X	X	

	Test well 1	Test well 1-X		
	125-145	350	395	500
Caprifoliipites tantulus Frederiksen, 1980	X		X	
Cupanieidites orthoteichus Cookson & Pike, 1954	X		X	
Momipites annulatus Frederiksen & Christopher, 1978	X		?	
Myrtaceidites parvus Cookson & Pike, 1954	X		X	
Nyssa kruschii (Potonie, 1931) Frederiksen, 1980	X	X	X	
Rhoipites angustus Frederiksen, 1980	X	X	X	
Tetracolporopollenites lesquereuxianus (Traverse, 1955) Frederiksen, 1980	X	X	X	
Tetracolporopollenites longipollinius (Traverse, 1955) Frederiksen, 1980	X	X	X	
Triatriopollenites sp. (*Myrica* type)	X	X	X	
Alnus vera (Potonie, 1931) Martin & Rouse, 1966	X			X
Araliaceoipollenites granulatus (Potonie, 1931) Frederiksen, 1980	X	X	X	X
Carya (large grains)	X	X	X	X
Cupuliferoipollenites spp.	X	X	X	X
Momipites coryloides Wodehouse, 1933	X	X	X	X
Momipites microfoveolatus (Stanley, 1965) Nichols, 1973	X	X	X	X
Platanus occidentaloides Frederiksen, 1980	X	X	X	X
Polyatriopollenites vermontensis (Traverse, 1955) Frederiksen, 1980	X			X
Pseudolaesopollis ventosa (Potonie, 1931) Frederiksen, 1979	X	X	X	X
Quercoidites inamoenus (Takahashi, 1961) Frederiksen, 1980	X		X	X
Rhoipites latus Frederiksen, 1980	X	X		X
Salixipollenites parvus Frederiksen, 1980	X	X		X
Siltaria pacata (Pflug *in* Thomson & Pflug, 1953) Frederiksen, 1980	X			X
Siltaria cf. *S. scabriextima* Traverse, 1955	X	X	X	X
Tetracolporopollenites megadolium (Potonie, 1931) Frederiksen, 1980	X	X	X	X
Ulmipollenites undulosus Wolff, 1934	X			X
Verrutricolporites spp.	X	X		X
Rousea monilifera Frederiksen, 1980		X		
Araliaceoipollenites profundus Frederiksen, 1980			X	
Casuarinidites cf. *C. granilabratus* (Stanley, 1965) Srivastava, 1972			X	
Cyrillaceaepollenites megaexactus (Potonie, 1931) Potonie, 1960			X	
Ephedra claricristata Shakhmundes, 1965			X	
Ericipites aff. *E. ericius* (Potonie, 1931) Potonie, 1960			X	
Hippocrateaceaedites sp.			X	
Liliacidites vittatus Frederiksen, 1973			X	
Symplocos gemmata Frederiksen, 1980			X	
aff. *Symplocospollenites* of Tschudy, 1973			X	
Cyrillaceaepollenites kedvesii Frederiksen, 1980			X	X
Gothanipollis cockfieldensis Engelhardt, 1964			X	X
Alangiopollis spp.				?
Betula sp.				X
Celtis sp.				X
Eucommia type				X
Gleicheniidites senonicus Ross, 1949				X
Graminidites gramineoides (Meyer, 1956) Krutzsch, 1970				X
Lycopodium hamulatum (Krutzsch, 1959) Frederiksen, 1980				X
Platycarya platycaryoides (Roche, 1969) Frederiksen & Christopher, 1978				X

However, the sporomorphs in the upper part of the Flour Island Formation of the Fort Pillow well have rather long ranges and thus are not the most useful taxa for biostratigraphic correlation. In the New Madrid hole, the lithologic boundary at 1,048 ft between the Memphis Sand and the Flour Island Formation coincides well with the contact between the middle and lower Eocene determined probably to be at about 1,055 ft according to sporomorphs.

The top of the Paleocene in New Madrid well 1-X is probably at about 1,105 ft; in the cuttings sample from 1,105-1,110 ft, the following sporomorphs have actual or apparent range tops:

Basopollis obscurocostata Tschudy 1975 (2)
Faguspollenites sp. of Frederiksen 1980b (3)
Insulapollenites rugulatus Leffingwell 1971 (probable) (2)
Momipites tenuipolus group, cf. *Platycarya* (1)
Momipites strictus Frederiksen & Christopher 1978 (possible) (4)
Paraalnipollenites confusus (Zaklinskaya 1963) Hills & Wallace 1969 (3)
Pistillipollenites mcgregorii Rouse 1962 (2)
Retitrescolpites angululuminosus (Anderson 1960) Frederiksen 1979 (4)
Tricolpites sp. (3)

The taxon marked (1), *Momipites tenuipolus* group with affinities to *Platycarya,* is probably an early Eocene form. Taxa marked (2) range from the lower Eocene to the Paleocene. Taxa marked (3) have ranges that are not yet definitely established, but thus far they have not been observed above the Paleocene in the Gulf Coast, whereas taxa marked (4) are those rather certain not to range above the Paleocene. In short, this sample is Paleocene but probably includes cavings from the lower Eocene. *Basopollis obscurocostata, Faguspollenites* sp., *Insulapollenites rugulatus* and *Paraalnipollenites confusus* are not known to range below the upper Paleocene (lower Sabinian) on the Gulf Coast.

Moore and Brown (1969) divided the Wilcox Group (which corresponds more or less to the Sabinian Provincial Stage) of the Fort Pillow well, in descending order, into the Flour Island Formation (mainly silt and clay), the Fort Pillow Sand, and the Old Breastworks Formation (mainly silt). In New Madrid test well 1-X, the top of the Fort Pillow Sand is at 1,186 ft, and the Old Breastworks Formation was tentatively identified as extending from 1,339 to 1,377 ft on the basis of cuttings and geophysical logs. The biostratigraphic contact between the Eocene and Paleocene in the Fort Pillow well could not be determined, but sporomorphs suggested that at least the lower half of the Old Breastworks Formation is Paleocene (R.H. Tschudy, *in* Moore and Brown, 1969). In the New Madrid well, the contact between the Eocene and Paleocene falls within the Flour Island Formation (fig. 2). Thus, the lower Eocene part of the Wilcox Group in the New Madrid well is much thinner than the upper Paleocene part of the Wilcox. Similar relative thicknesses of the lower Eocene and upper Paleocene are found throughout the Gulf Coast (Bennison, 1975).

Table 2. Dinoflagellates and other plankters in cuttings from 1,340-1,405 ft in New Madrid test well 1-X.

	1,340-1,350	1,350-1,360	1,360-1,370	1,370-1,380	1,380-1,390	1,390-1,405
Cordosphaeridium gracile (Eisenack, 1954) Davey & Williams, 1966	X					
Spiniferites spp.	X	X				
Spinidinium densispinatum Stanley, 1965	X	?		X		X
Small peridinioid forms	X	X	X	X	X	X
Reworked Cretaceous forms *(Chatangiella, Cyclonephelium, Spongodinium delitiense, Odontochitina costata)*	X	X	X	X	X	X
Pediastrum	X	X	X	X	X	X

Palynomorphs were examined from cuttings representing 10-15 ft intervals from 1,340 to 1,405 ft in order to determine, if possible, the position of the boundary between the upper and lower Paleocene (Sabinian-Midwayan Provincial Stage boundary) in the New Madrid 1-X well. These cuttings contain definite Paleocene sporomorphs, but the Paleocene species are few in number, and all have long ranges. Therefore, sporomorphs do not indicate whether the Sabinian-Midwayan boundary is within the interval studied. Table 2 is a list of the dinoflagellate taxa found in these samples. The specimens are poorly preserved, but all six samples contain similar dinoflagellate floras consisting mainly of small peridinioid forms and reworked Cretaceous specimens. If *Spinidinium densispinatum* is indigenous in these samples, its presence suggests a Midwayan age; this species has been found in the Naheola and Clayton Formations (Midwayan), but not in the Tuscahoma or Nanafalia Formations (lower Sabinian) in eastern Alabama and western Georgia (Edwards, 1980, and unpublished data). If the interval from 1,339 to 1,377 ft is Midwayan, then it may belong to the Porters Creek Clay, and the Old Breastworks Formation may be missing from the New Madrid test well. However, the interval correlates in stratigraphic position, and generally in lithology, with the Old Breastworks Formation of the Fort Pillow well. Furthermore, on the basis of its stratigraphic position and the dinoflagellate data, the interval seems likely to correlate with the upper Midwayan Naheola Formation of the eastern Gulf Coast. In short, study of the New Madrid samples suggests that correlatives of the Naheola Formation may extend as far north as southeastern Missouri and that the Old Breastworks Formation in the New Madrid well, and presumably also in the Fort Pillow well, may belong to the Midway Group rather than to the Wilcox Group to which the formation was assigned by Moore and Brown (1969).

Core samples from 1,417 to 1,702 ft were examined for calcareous nannofossils. Five of these samples, from 1,417 to 1,537.5 ft, are barren. Eleven samples from the lower part of the Porters Creek Clay at 1,544 to 1,671 ft contain an assemblage (Table 3) from Martini's (1971) Zone NP3 (Danian), and two samples from the Clayton Formation at 1,698.5 and 1,702 ft contain an assemblage possibly from Zone NP2 (Danian). Bybell (1980) examined calcareous nannofossils from the type area of the Midwayan Provincial Stage (lower Paleocene) in western Alabama. In that area, the upper member of the Porters Creek Clay, the Matthews Landing Marl Member, can be placed in Zone NP4, the upper member of the Clayton Formation, the McBryde Limestone Member, can be placed in Zone NP3, and

Table 3. Calcareous nannofossils in lower Paleocene core sample from New Madrid test well 1-X. Depth in ft.

	Porters Creek Clay 1,544-1,671 Zone NP3	**Clayton Formation 1,698.5-1,702 Zone NP2?**
Chiasmolithus consuetus (Bramlette & Sullivan, 1961)	X	
Neochiastozygus concinnus (Martini, 1961)	X	
Braarudosphaera bigelowi (Gran & Braarud, 1935)	X	X
Cepekiella aff. *C. lumina* (Sullivan, 1965)	X	X
Coccolithus pelagicus (Wallich, 1877)	X	X
Cruciplacolithus tenuis (Stradner, 1961)	X	X
Ericsonia subpertusa Hay & Mohler, 1967	X	X
Lanternithus sp. cf. *L. duocavus* Locker, 1967	X	X
Markalius inversus (Deflandre, 1954)	X	X
Thoracosphaera spp.	X	X
Zygodiscus sigmoides Bramlette & Sullivan, 1961	X	X
Braarudosphaera discula Bramlette & Riedel, 1954		X

the lower member of the Clayton, the Pine Barren Member, can be placed in either Zone NP3 or NP2. Therefore, the lower part of the Porters Creek Clay in the Missouri core is correlative with at least the upper part of the Clayton, and perhaps also with the lower part of the Porters Creek Clay, of western Alabama (fig. 3). The Clayton Formation in the Missouri core, on the basis of calcareous nannofossils, may be correlative with the lower part of the Clayton in western Alabama. Reworked Cretaceous calcareous nannofossils were also found in the core samples from 1,698.5 and 1,702 ft, including *Arkhangelskiella cymbiformis* Bekshina, 1959, *Micula staurophora* (Gardet, 1955), and *Zygodiscus spiralis* Bramlette & Martini, 1964, which range from the Maestrichtian to the upper Campanian in southwestern Tennessee, eastern and northeastern Mississippi, and western Alabama.

Ostracodes were found in 11 samples of the Porters Creek Clay and Clayton Formation of New Madrid well 1-X (Table 4), but identifiable specimens were recovered only from four samples between 1,670.5 and 1,699 ft (Table 5). The sample from 1,670.5 ft (lower part of the Porters Creek Clay) contains several species that have not been recorded below the Wills Point Formation in Texas (Alexander, 1934), and the assemblage (Table 5) is different from that of a reference sample from the middle part of the Porters Creek Clay of western Alabama. Thus, the test well sample from 1,670.5 ft seems to be correlative with the lower part of the Porters Creek Clay or the upper part of the Clayton Formation (McBryde Limestone Member) of Alabama and eastern Mississippi (fig. 3). The assemblage in the sample from 1,686.5 ft (Porters Creek Clay; Table 5) suggests that this sample is no younger than the faunal assemblages from the Kincaid Formation of Texas or the Clayton Formation of the eastern Gulf Coast (Alexander, 1934). The Clayton samples from 1,697.3 and 1,699 ft contain an early Paleocene (Danian) assemblage that indicates correlation with the lower part of the Clayton Formation (Pine Barren Member) of western Alabama and the lower part of the Kincaid Formation of Texas (Alexander, 1934; Hazel, 1968; Smith, 1978).

Thirty taxa of foraminifers were found in the Porters Creek Clay and Clayton Formation (Table 6). All were benthic forms except *Globorotalia compressa* at 1,670.5 ft in the Porters Creek Clay. This species has a known range from the middle of Blow's

<table>
<tr><th>SERIES</th><th>STAGE</th><th>TEXAS</th><th>NEW MADRID WELL 1-X, MISSOURI</th><th colspan="2">WESTERN ALABAMA</th></tr>
<tr><td rowspan="5">PALEOCENE (LOWER PART)</td><td rowspan="5">MIDWAYAN</td><td></td><td>OLD BREASTWORKS (?) FORMATION</td><td colspan="2">NAHEOLA FORMATION</td></tr>
<tr><td rowspan="3">WILLS POINT FORMATION</td><td rowspan="4">PORTERS CREEK CLAY</td><td rowspan="4">PORTERS CREEK CLAY</td><td>MATTHEWS LANDING MARL MEMBER</td></tr>
<tr><td rowspan="3">UNNAMED MEMBER</td></tr>
<tr><td rowspan="2">KINCAID FORMATION</td><td rowspan="2">CLAYTON FORMATION</td><td rowspan="2">CLAYTON FORMATION</td><td>MCBRYDE LIMESTONE MEMBER</td></tr>
<tr><td>PINE BARREN MEMBER</td></tr>
</table>

Figure 3. Tentative correlation of Midwayan (lower Paleocene) formations of New Madrid test well 1-X with lithologic units of the Gulf Coast. Thicknesses of units not to scale.

(1969) Zone P3 to the middle of Zone P1. This range is considered by Hardenbol and Berggren (1978) to be equivalent to calcareous nannofossil Zones NP4 through NP2, or earliest Thanetian to late Danian. Many of the benthic species in the two Porters Creek samples from New Madrid well 1-X have been reported from both the Porters Creek and Clayton of the Gulf Coast but do not extend up into the Naheola Formation, which overlies the Porters Creek. Detailed published foraminiferal biostratigraphies of the Midwayan are largely lacking, but several of the species found appear to be restricted to the Porters Creek and the uppermost part of the Clayton; they include *Clavulinoides midwayensis*, *Anomalina midwayensis*, and *Robulus* cf. *R. rosettus*. On the basis of these species, it appears most likely that the New Madrid 1-X samples from 1,670.5 and 1,686.5 ft are equivalent to the Porters Creek or uppermost part of the Clayton of the Gulf Coast and not to the lower half of the Clayton of that region. The benthic foraminifers in the Clayton samples from 1,697.3 and 1,699 ft in the New Madrid test well are Midwayan in age but have rather long ranges in the Gulf Coast; most of the species are known from the upper part of the Porters Creek Clay (Matthews Landing Marl Member) to the lower part of the Clayton Formation (Pine Barren Member).

Only three species of mollusks were found in the lower Paleocene core samples of test well 1-X. *Ledina smirna* (Dall, 1898) was found at 1,543, 1,567, and 1,608 ft, *Nucula* sp. at 1,543 ft, and *Gryphaeostrea pulaskensis* (Harris, 1894) at 1,686.5, 1,694.5, 1,695, and 1,699 ft. However, the two taxa identified to species level have well documented stratigraphic and geographic ranges. *Ledina smirna* has been reported from the Kincaid and Wills Point Formations (Midwayan, lower Paleocene) of Texas (Gardner, 1933), from Midwayan strata of Arkansas, Tennessee, Mississippi, and Alabama (Harris, 1896), and from the

Table 4. Protistan and animal fossils in lower Paleocene core samples from New Madrid test well 1-X.

Depth in feet	Lithology	Mollusks	Foraminifers	Ostracodes	Others
1,456	Clay, carbonaceous	—	—	—	—
1,470	do.	—	—	—	—
1,479	Clay	—	?	—	Fish scales
1,499	Clay, slightly silty	—	Scarce	—	—
1,509	do.	—	Scarce, small	—	—
1,543	do.	Common	Scarce, very small	—	—
1,567	do.	Fragments	Scarce, small, fragile	Scarce, small, fragile	—
1,577	do.	—	Fragments	Fragments	—
1,608	do.	Some present	Few, poorly preserved	Few, poorly preserved	—
1,646	do.	Trace	Rare	—	—
1,660	do.	—	Small, in pockets	—	Echinoid spine; fish scale
1,664	do.	—	Scarce, fragile	Scarce, fragile	Fish scales
1,670.5	Clay, silty, glauconitic	—	Common	Common	—
1,682	do.	—	do.	Fragments	—
1,686.5	do.	Common	do.	Common	Fish scales
1,694.5	do.	do.	do.	do.	—
1,695	do.	Fragments common	do.	do.	—
1,697.3	Sand, glauconitic, fine	do.	do.	do.	—
1,699	Sand, glauconitic, medium to coarse	Abundant	Abundant	Abundant	—

Matthews Landing Marl Member of the Porters Creek Clay in Alabama (Toulmin, 1977). This species is found mainly in silty and clayey strata (Porters Creek lithofacies) rather than in sandy strata (Clayton lithofacies). *Gryphaeostrea pulaskensis* occurs in the Kincaid Formation of Texas (Gardner, 1933), in Midwayan units of Arkansas, Tennessee, Mississippi, Alabama, and Georgia (Harris, 1896), and in the lower part of the Clayton Formation (Pine Barren Member) of Alabama (Toulmin, 1977). The occurrence data for *Ledina smirna* and *Gryphaeostrea pulaskensis* suggest a middle to lower Paleocene placement for the 1,543-1,699 ft interval of the core.

The lower part of the Clayton Formation contains reworked Late Cretaceous mollusks in many areas of Mississippi, Tennessee, and Missouri (Stephenson, 1955; Sohl, 1960). However, these were not identified among the fossils from the Clayton in test well 1-X.

Dinflagellate taxa in core samples from 1,417 to 1,698.5 ft are listed in Table 7. Dinoflagellates from 1,417 ft are poorly preserved, and most specimens are reworked Cretaceous forms. For example, the specimens of *Chatangiella* have omegaform periarcheopyles and 3I endarcheopyles; such forms are known only from the Campanian to Santonian (except in the Arctic) according to Lentin and Williams (1976). The genus *Dinogymnium* ranges from Maestrichtian to Coniacian. Some of the other forms, such as *Deflandrea* cf. *D. pannucea* and the small peridinioid forms, may possibly be indigenous to the Porters Creek Clay: the ranges of these forms are poorly known, but the specimens did not stain as darkly as those of the obviously reworked species. The core samples from 1,433-1,435 and 1,482 ft contain only a few dinoflagellates, mainly small peridinioid forms. The samples from 1,544 and 1,591 ft are very similar to each other in their dinoflagellate

Table 5. Ostracodes in lower Paleocene core samples from New Madrid test well 1-X. Depth in ft.

	Porters Creek Clay		Clayton Formation	
	1,670.5	1,686.5	1,697.3	1,699
Eucythere midwayensis Alexander, 1934	X			
Hermanites midwayensis (Alexander, 1934)	X			
Krithe perattica Alexander, 1934	X			
Opimocythere interrasilis (Alexander, 1934)	X			
Paracypris parapiculata (Alexander, 1934)	X			
Phacorhabdotus formosus (Alexander, 1934)	X			
Acanthocythereis washingtonensis Hazel, 1968	X		X	
Bairdia sp.	X		X	
Hazelina n. sp. A (=*Repandocosta* sp. A of Hazel, 1967)	X	X	X	
Brachycythere plena Alexander, 1934	X	X	X	X
Cytherella tumidosa Alexander, 1934	X	X	X	X
Acanthocythereis sp.		X		
"Cythereis" cancellosa Alexander, 1934		X		
Cytherelloidea sullivani Smith, 1978		X		
Haplocytheridea fornicata (Alexander, 1934)		X		
Loxoconcha cf. *L. perdecora* Alexander, 1934		X		
Phacorhabdotus sculptilis Alexander, 1934		X		
Xestoleberis truncata Alexander, 1934		X		
Hermanites gibsoni Hazel, 1968		X	X	
Clithrocytheridea sp.			X	
Cytherelloidea truncata Schmidt, 1948			X	
Haplocytheridea macrolaccus munseyi (Hazel, 1968)			X	
Hermanites cf. *H. hadropleura* Hazel, 1968			X	
Opimocythere hazeli Smith, 1978			X	
Phractocytheridea ruginosa (Alexander, 1934)			X	
Bairdia suborbiculata Alexander, 1934			X	X
Hermanites aff. *H. plusculmensis* (Schmidt, 1948)				X

floras, and the specimens are reasonably well preserved. This flora is Paleocene in age, but the species present either have long ranges, or else they are new species whose ranges are not yet known in detail. In contrast, the dinoflagellate assemblages from 1,646 ft (Porters Creek) and 1,698.5 ft (Clayton) can be assigned an early Paleocene age; very similar floras are found in the Brightseat Formation of Maryland and in the Clayton Formation of Alabama and Georgia (Edwards, 1980, and unpublished data).

Six core samples were examined for sporomorphs from the Porters Creek Clay, from 1,417 to 1,646 ft (Table 8). One useful core sample was examined from the Clayton Formation at 1,698.5 ft; the Clayton core sample from 1,702 ft was barren of palynomorphs. The upper half of the Porters Creek Clay in New Madrid well 1-X has a sporomorph flora that includes several elements not known to range below the Sabinian (below the upper Paleocene) on the Gulf Coast, including *Paraalnipollenites confusus*, *Labrapollis globosa*, and *Milfordia incerta*. However, all the species found in the lower part of the Porters Creek of the test hole have been found in the Clayton of the Gulf Coast except *Margocolporites cribellatus*. Of taxa found only or perhaps only in the Clayton in the New Madrid well, *Interpollis paleocenica* ranges throughout the Paleocene in the Gulf Coast, and *Momipites fragilis* may be reworked from the Cretaceous in samples from both the Gulf Coast and the New Madrid hole. Previous studies of the middle and lower Midwayan of the Gulf Coast and South Carolina also showed that the sporomorph taxa particularly of early Porters Creek age are very similar to those of Clayton age

Table 6. Foraminifers in lower Paleocene core samples from New Madrid test well 1-X. Depth in ft.

	Porters Creek Clay		Clayton Formation	
	1,670.5	1,686.5	1,697.3	1,699
Clavulinoides midwayensis Cushman, 1936	X			
Discorbis sp.	X			
Ellipsonodosaria plummerae Cushman, 1940	X			
Globorotalia compressa (Plummer, 1927)	X			
Pseudoparella cf. *P. exigua* (Brady, 1884)	X			
Anomalina midwayensis (Plummer, 1927)	X	X		
Vaginulina gracilis Plummer, 1927	X	X		
Robulus cf. *R. rosettus* (Gumbel, 1870)	X	X	X	
Dentalina colei Cushman & Dusenbury, 1934	X	X	X	X
Valvulinaria sp.	X	X	X	X
Cibicides alleni (Plummer, 1927)		X		
Cibicides praecursorius (Schwager, 1883)		X		
Cibicides sp. A		X		
Cibicides sp. B		X		
Ellipsonodosaria sp.		X		
Eponides sp.		X		
Gyroidina subangulata (Plummer, 1927)		X		
Marginulina cf. *M. glabra* d'Orbigny, 1826		X		
Nodosaria affinis Reuss, 1874		X		
Pseudoglandulina pygmaea (Reuss, 1851)		X		
Pullenia quinqueloba (Reuss, 1851)		X		
Globulina gibba d'Orbigny, 1846		X	X	
Cibicides cf. *C. neelyi* Jennings, 1936		X	X	X
Guttulina problema d'Orbigny, 1846		X	X	X
Robulus midwayensis (Plummer, 1927)		X	X	X
Cibicides howelli Toulmin, 1941			X	
Vaginulina longiforma (Plummer, 1927)			X	
Virgulina cf. *V. naheolensis* Cushman, 1944			X	
Globulina rotundata (Bornemann, 1855)				X
Guttulina sp.				X

(Herrick and Tschudy, 1967; Tschudy, 1973b, 1975; Frederiksen, 1980b, c).

To summarize the lower Paleocene core samples (fig. 3), sporomorphs suggest that in New Madrid well 1-X, the upper part of the Porters Creek Clay correlates with the upper part of the Porters Creek and possibly also in part with the overlying upper Midwayan Naheola Formation of the eastern Gulf Coast. Data from many kinds of fossils agree that the lowermost part of the Porters Creek in the test well probably correlates with the upper part of the Clayton Formation of the eastern Gulf Coast and with the Kincaid Formation of Texas. The entire thin Clayton of the test well probably correlates with the lower part of the thick Clayton of the eastern Gulf Coast.

Upper Cretaceous

Nine core samples from 1,770 to 1,901.5 ft in test well 1-X were examined for palynomorphs (fig. 4). Sporomorphs recovered from these samples were compared with those illustrated by Wolfe (1976) from the Upper Cretaceous of the Raritan and Salisbury embayments in the Middle Atlantic States (dashed range lines in fig. 4); the age assigned to the New Madrid samples is based on the range chart presented by Wolfe. All nine samples have a similar palynological composition. Spores and pollen are generally abundant and well pre-

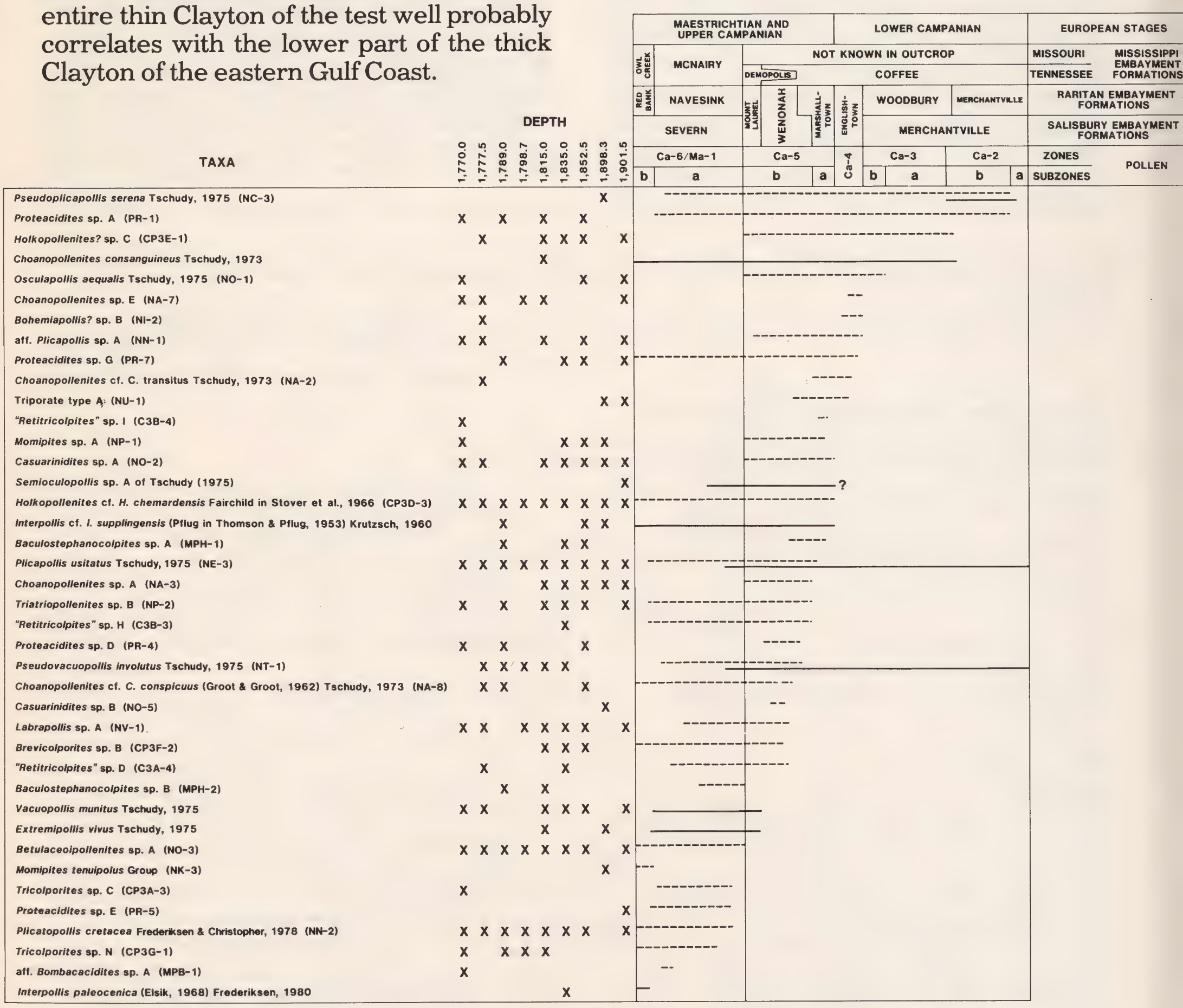

Figure 4. Late Cretaceous sporomorphs from samples between 1,770 and 1,901.5 ft in New Madrid test well 1-X. The alphanumeric code in parentheses following each binomen is Wolfe's (1976) species designation. Dashed range lines are from Wolfe's (1976) range chart; solid range lines are from Tschudy (1973b, 1975).

Table 7. Dinoflagellates and acritarchs in lower Paleocene core samples from New Madrid test well 1-X. Depth in ft.

	Porters Creek Clay				Clayton Formation
	1,417	1,544	1,591	1,646	1,698.5
★*Chatangiella* spp.	X				
Deflandrea cf. *D. pannucea* Stanley, 1965	X				
★*Dinogymnium* sp.	X				
Hystrichosphaeridium tubiferum? (Ehrenberg, 1838) Deflandre, 1937	X				
★*Isabelidinium acuminata*? (Cookson & Eisenack, 1958) Stover & Evitt, 1978	X				
Spongodinium delitiense	X				
★*Spinidinium vestitum*? Brideaux, 1971	X				
Fibrocysta bipolare (Cookson & Eisenack, 1965) Stover & Evitt, 1978	X		X		
Small peridinioid forms	X	X	X		X
Achomosphaera sp.		X	X		
Apectodinium cf. *A. homomorphum* (Deflandre & Cookson, 1955) Lentin & Williams, 1977		X	X		
Cordosphaeridinium gracile (Eisenack, 1954) Davey & Williams, 1966		X	X	X	
Deflandrea cf. *D. darmooria* Cookson & Eisenack, 1965		X		X	
Spiniferites ramosus granomembranaceous (Davey & Williams, 1966) Lentin & Williams, 1973		X	X	X	
Cordosphaeridium multispinosum Davey & Williams, 1966	X	X			X
Palaeocystodinium cf. *P. australinum* (Cookson, 1965) Lentin & Williams, 1976		X	X	X	X
Veryhachium hyalodermum (Cookson, 1956) Schaarschmidt, 1963		X	X	X	X
Cordosphaeridinium inodes (Klumpp, 1953) Eisenack, 1963			X		X
Deflandrea obscura Drugg, 1967			X		X
Fibradinium annetorpense Morgenroth, 1968			X	X	X
Andalusiella polymorpha (Malloy, 1972) Lentin & Williams, 1977				X	
Danea californica (Drugg, 1967) Damassa, 1979				X	
Impagidinium sp.				X	
Spiniferites cornutus (Gerlach, 1961) Sarjeant, 1970				X	
Trigonopyxidium ginella (Cookson Eisenack, 1960) Downie & Sarjeant, 1964				X	
Deflandrea cf. *D. diebelii* sensu Drugg, 1967				X	X
Membranosphaera maastrichta Norris & Sarjeant, 1965				X	X
Palaeoperidinium pyrophorum (Ehrenberg, 1838) Sarjeant, 1967				X	X
Palaeotetradinium caudatum Benson, 1976				X	X
Spiniferites septatus (Cookson & Eisenack, 1967) McLean, 1971				X	X
Adnatosphaeridium sp.					X
Deflandrea magnifica Stanley, 1965					X
Fibrocysta sp. A of Edwards, 1980					X
Spinidinium sp.					X
Spiniferites spp.					X
Thalassiphora pelagica (Eisenack, 1954) Eisenack & Gocht, 1960					X

★ = Cretaceous taxa.

served. Each sample contains assemblages of two apparent ages (fig. 4). One assemblage consists of species indicative of a Maestrichtian to latest Campanian Age; the other assemblage consists of species indicative of an early late or early Campanian Age.

Two hypotheses that can be advanced to explain assemblages of two different ages in each sample are:

1. The ranges of the species in the Mississippi Embayment differ from those in the Middle Atlantic States, and
2. Lower upper or upper lower Campanian deposits have been reworked into deposits of Maestrichtian to latest Campanian Age.

We accept the second hypothesis as the best explanation because several forms were observed in the samples that according to Tschudy (1973b, 1975) and others have concurrent ranges only in Maestrichtian to uppermost Campanian deposits in the Mississippi Embayment (*Vacuopollis munitus, Semioculopollis* sp. A, *Choanopollenites consanguineus, Extremipollis vivus, Interpollis* cf. *I. supplingensis, Interpollis paleocenica;* solid range lines in fig. 4). Also included in these assemblages are a wide variety of triatriate forms of *Momipites* and *Plicatopollis* that are typically associated with deposits of early Tertiary or latest Cretaceous age. Reworking of Late Cretaceous fossils continued for millions of years in southeastern Missouri; Maestrichtian and Campanian palynomorphs are found throughout the lower Tertiary formations of the New Madrid wells, and Maestrichtian to late Campanian calcareous nannofossils are found in the Clayton.

The Cretaceous pollen zonation for the Gulf and Atlantic Coastal Plains was originally established on the basis of stratigraphic sections in the Middle Atlantic States, and it has not been ascertained to what extent this zonation can be applied to the Mississippi Embayment. However, figure 4 shows that if we assume reworking, all nine samples appear to fall into pollen zone CA-6/MA-1 of Wolfe (1976). A vertical line in figure 4 suggests the oldest possible age of the samples, based on assumed reworking. The entire interval between 1,770 and 1,901.5 ft in the New Madrid core would, therefore, correlate with the Navesink Formation and Red Bank Sand of New Jersey and with the Severn Formation of Maryland. These East Coast units are considered early Maestrichtian in age on the basis of dinoflagellates (Benson, 1976; Whitney, 1976; May, 1980a, b) or early Maestrichtian to late Campanian on the basis of mollusks (Sohl and Mello, 1970).

Dinoflagellates and acritarchs, which are generally indicators of brackish-water to marine environments of deposition, are rare in all nine core samples examined for palynomorphs from 1,770 to 1,901.5 ft. Of twelve core samples from this interval examined for calcareous nannofossils, all but one are barren. The sample from 1,835 ft contains *Cruciplacolithus tenuis, Ericsonia subpertusa, Markalius inversus, Thoracosphaera* spp., and *Zygodiscus sigmoides,* which are probably from Paleocene Zone NP2. However, this sample contains sporo-

Table 8. Sporomorphs in lower Paleocene core samples from New Madrid test well 1-X. Depth in ft.

	Porters Creek Clay						Clayton Formation
	1,417	1,433-1,435	1,482	1,544	1,591	1,646	1,698.5
Momipites dilatus Fairchild *in* Stover *et al.*, 1966	X						
Momipites flexus Frederiksen, 1979	X	X					
Paraalnipollenites confusus (Zaklinskaya, 1963) Hills & Wallace, 1969	X		X				
Trudopollis plena Tschudy, 1975	X	X	X				
Bombacacidites reticulatus Krutzsch, 1961	X			X			

	Porters Creek Clay					Clayton Formation
	1,417	**1,433-1,435**	**1,482**	**1,544**	**1,591**	**1,646**	**1,698.5**
Margocolporites cribellatus Srivastava, 1972	X			X	X	X	
Pseudoplicapollis limitata Frederiksen, 1978	?	X	X	X	X	X	
Ulmipollenites krempii (Anderson, 1960) Frederiksen, 1979	X		X	X		X	
Betula infrequens Stanley, 1965	X	X		X	X	X	X
Choanopollenites alabamicus (Srivastava, 1972) Frederiksen, 1979	?	X	X	X	X	X	?
Choanopollenites aff. *C. consanguineus* Tschudy, 1973	X					X	X
Classopollis spp.	X	X	X	X	X	X	X
Momipites microfoveolatus (Stanley, 1965) Nichols, 1973	X		X	X	X	X	X
Momipites tenuipolus group	X		X	X	X	X	X
Pseudoplicapollis serena Tschudy, 1975	X	X	X	X			X
Tricolpites asper Frederiksen, 1978	X		X	?			?
Momipites strictus Frederiksen & Christopher, 1978		X	X	?			
Momipites coryloides Wodehouse, 1933		X	X	X		X	?
Aesculiidites circumstriatus (Fairchild *in* Stover *et al.*, 1966) Elsik, 1968			?				
Labrapollis globosa (Pflug *in* Thomson & Pflug, 1953) Krutzsch, 1968			X				
Choanopollenites conspicuus (Groot & Groot, 1962) Tschudy, 1973			X	X	X	X	
Favitricolporites baculoferus (Pflug *in* Thomson & Pflug, 1953) Srivastava, 1972			X	X	X		X
Chenopodipollis spp.				X			
Milfordia incerta (Pflug & Thomson *in* Thomson & Pflug, 1953) Krutzsch, 1961				X			
Nudopollis thiergartii (Thomson & Pflug, 1953) Pflug, 1953				X			
Osculapollis? colporatus Frederiksen, 1980				X			
Choanopollenites discipulus Tschudy, 1973				X	X	X	
Interporopollenites turgidus Tschudy, 1975				X	X	X	
Nudopollis terminalis (Pflug & Thomson *in* Thomson & Pflug, 1953) Pflug, 1953				X	X	X	
Ephedra voluta type				X	X		X
Holkopollenites chemardensis Fairchild *in* Stover *et al.*, 1966				X	?	?	X
Momipites fragilis Frederiksen & Christopher, 1978						?	X
Interpollis paleocenica (Elsik, 1968) Frederiksen, 1980							X

morph assemblages of Maestrichtian to latest Campanian(?) and of Campanian Ages and has no sporomorphs restricted to the Tertiary. The sample was a medium-dark-gray, carbonaceous, very micaceous mudstone. We conclude that the nannofossils in the sample from 1,835 ft are probably from drilling mud infiltration.

Lithologically, the Upper Cretaceous strata recovered from New Madrid well 1-X are fine to coarse quartzose sand and subordinate micaceous, carbonaceous clay, and the whole recovered sequence is assignable to the McNairy Sand. In southwestern Tennessee and northern Mississippi, the Ripley Formation can be divided into members, and the McNairy Sand Member is in the upper part of the Ripley (figure 3; Sohl, 1960). However, to the north, in Missouri, Kentucky, and Illinois, strata of Ripley age are all nonmarine to nearshore marine sand and clay, similar to the McNairy Sand Member of the Ripley Formation to the south, and at the northern end of the Mississippi Embayment all strata of Ripley age are termed McNairy Sand.

No paleontological evidence was found that the Owl Creek Formation is present in New Madrid well 1-X. The Owl Creek forms the top of the Cretaceous section in much of the northern Mississippi Embayment (Sohl, 1960) and is probably middle to early Maestrichtian in age (Sohl and Mello, 1970); it overlies the Ripley Formation or the McNairy Sand as far north as Crowleys Ridge in Scott and Stoddard Counties, Mo., 50 miles to the northwest of the New Madrid test wells (Stephenson, 1955). In contrast to the McNairy, the Owl Creek is shelly and distinctly glauconitic; on Crowleys Ridge, the Owl Creek is as much as 11 ft thick, and it is thought to be as thick as 100 ft in the subsurface of southeastern Missouri (Grohskopf and Howe, 1961). The base of the Clayton Formation in New Madrid well 1-X is at 1,704.5 ft according to fossils in the core and footages marked on the core box; the base of the Clayton is at 1,703 ft on the basis of the geophysical logs (Crone and Russ, 1979, Appendix 2). The logs indicate that, if present, the Owl Creek Formation is mainly silt or clay and is perhaps only 3 ft thick in the New Madrid well (Crone, 1981). Unfortunately, no cores were recovered from 1,704.5 to 1,769 ft; thus, we have no reliable samples from the Owl Creek interval.

Marine to nonmarine strata of pre-McNairy, Campanian Age and more than 100 ft thick are reported in the subsurface of southeastern Missouri by Grohskopf and Howe (1961), but these strata were not identified in New Madrid well 1-X. However, no cores were recovered from the sand section between 1,902.5 ft and the top of the Paleozoic dolostone at 2,023 ft. Marine Campanian rocks must have been exposed updip from this area at least until late Eocene time because, as noted previously, reworked marine and terrestrial Campanian fossils are found in upper Eocene to Maestrichtian rocks of test wells 1 and 1-X.

In summary, all of the Cretaceous rocks recovered in New Madrid well 1-X are late Cretaceous, Maestrichtian and possibly latest Campanian, in age and are assignable to the McNairy Sand; the Owl Creek Formation overlying the McNairy, and Campanian rocks underlying the McNairy, may be present in this area but were not recovered by coring.

Lower Paleozoic

Nine samples of the lower Paleozoic dolostone in test well 1-X were examined for conodonts and vertebrate remains. These samples included one core, from 2,027-2,028 ft, and cuttings from various intervals between 2,045 and 2,305 ft. The cored segment is a medium- to coarse-grained, medium gray dolostone. It is chiefly a dolomitized grainstone and contains white sparry patches and stripes that probably represent originally shelly material. These "ghosts" are now dolomite and not identifiable. Each sample processed for conodonts and vertebrate remains weighed between 0.75 and 3.8 kg, and a total mass of 22.05 kg was processed.

The only identifiable fossil recovered was one pyritized fragment from 2,045-2,050 ft. This fragment is probably a scale-bearing piece of *Anatolepis* Bockelie and Fortey 1976, a genus that includes the oldest known fish (see Repetski, 1978). Unfortunately, the known range of this genus is rather long, from early Middle Ordovician to Late Cambrian, which spans the age range of dolostones in this part of the midcontinent

(Grohskopf, 1955). However, previous experience in processing relatively large samples of midcontinent Ordovician and Cambrian rocks for conodonts has shown that Cambrian rocks commonly are barren of these fossils, whereas Ordovician samples of this size normally contain them. Therefore, the lack of conodonts from all Paleozoic samples processed from the New Madrid test well suggests that the Paleozoic bedrock is Cambrian. A Cambrian age here is also wholly in accord with Grohskopf's (1955, Pl. III) geologic map of pre-Cretaceous strata in this region and with the reported presence of Late Cambrian fossils in a well in Lake County, Tennessee, only about 8.5 miles southeast of the site of test well 1-X (J. Bridge, in Grohskopf, 1955, p. 127). The fossils from the Lake County well may be slightly older, but they are from below the highest Paleozoic strata there, and that well is located nearer the axis of the Pascola Arch.

IV. CRETACEOUS-TERTIARY PALEOECOLOGY AND GEOLOGIC HISTORY

Upper Cretaceous strata of the McNairy Formation (Maestrichtian and possibly upper Campanian) recovered from New Madrid well 1-X probably formed in nonmarine to nearshore marine environments. They contain only rare (reworked?) dinoflagellates, and they apparently lack calcareous fossils. However, at least trace amounts of glauconite are found throughout the Upper Cretaceous strata of the test well, and, especially in the lower part of the section, glauconite is common in some samples (see Crone, 1981). Therefore, at least some of the Upper Cretaceous beds must be marine. As noted in the section on biostratigraphy, no strata were recovered from New Madrid well 1-X that could be assigned to the marine Owl Creek Formation, the youngest Cretaceous formation (middle Maestrichtian) of the northern Mississippi Embayment.

The Clayton of New Madrid well 1-X is a glauconitic shelly marl grading upward into a glauconitic shelly sand. Mollusks, foraminifers, and ostracodes are abundant particularly in the marl (Table 4), but apparent taxon diversities of the calcareous fossils may be influenced as much by preservation and difficulties of recovering specimens from the indurated beds of the cored Clayton as they are by actual faunal diversities in the formation. For example, only three species of mollusks were recovered from the Clayton in New Madrid well 1-X; however, many species of bivalves and gastropods have been collected in southeastern Missouri from the outcropping Clayton (Matthes, 1933; Farrar, 1935), which represents a beach deposit according to Shourd and Winter (1980). The subsurface Clayton, closer to the axis of the embayment, undoubtedly formed in deeper water than the part of the formation in present outcrops. Assemblages of calcareous nannofossils, dinoflagellates, foraminifers, mollusks, and ostracodes in the Clayton of New Madrid well 1-X suggest normal marine conditions of deposition in perhaps relatively shallow water, but they are not definitive as to water depth.

The lower part of the Porters Creek Clay represents a widespread transgression of the early Paleocene sea (Stearns, 1957). In the northern part of the Mississippi Embayment, the Porters Creek is a massive silty clay that locally becomes sandy in its upper part; in addition, fossils are more common near the base than near the top (Caplan, 1954; Stearns, 1957; Koenig, 1961; Moore and Brown, 1969). The decrease in fossil abundance and diversity from the base of the formation upward is obvious from the sample analyses presented in Table 4. Shelly glauconitic sand and clay of the upper part of the Clayton grades, rather abruptly, upward into glauconitic silty clay of the Porters Creek; the fossil content of the Porters Creek decreases markedly upward as the silt and glauconite content decreases. Upward decreases in species diversities of dinoflagellates (Table 7) and foraminifers (Table 6) are particularly noticeable. Fossil assemblages indicate a normal marine environment of deposition, no doubt with shoaling water as Porters Creek time progressed, represented by the core samples as high as 1,670.5 ft and probably as high as 1,544 ft, but the dinoflagellate assemblages from the samples at 1,544 and 1,417 ft (Table 7) and the lack of calcareous nannoplankton from samples above 1,544 ft suggest that the upper part of the Porters Creek Clay was probably deposited in

brackish water. The absence or rarity of planktic foraminifers in all Porters Creek samples from the New Madrid well may reflect the distance of this area of deposition from the open Gulf, may indicate that the Porters Creek sea was too shallow to support depth-stratified planktic foraminifers, or may result from syndepositional or postdepositional leaching.

Fewer than half a dozen dinoflagellate species were found in the cuttings from 1,377 to 1,339 ft (Table 2), the silty interval probably of late Midwayan Age representing the uppermost part of the Porters Creek Clay or the Old Breastworks Formation. Futhermore, small peridinioid dinoflagellates and freshwater algae belonging to *Pediastrum* are present throughout this interval, also suggesting brackish water deposition or at least a nearby source of fresh water.

The history suggested by the New Madrid samples, of a transgression in Clayton-early Porters Creek time, followed by a regression that lasted until the end of Porters Creek and possibly until the end of Old Breastworks time, agrees well with the paleogeographic maps and interpretations of Stearns (1957). He shows the sea becoming progressively narrower during deposition of the Porters Creek Clay until, at the end of Porters Creek time, it occupied a long narrow bay that covered southeastern Missouri, northeastern Arkansas, western Tennessee, and southwestern Kentucky and had only a very restricted connection with the Gulf of Mexico.

The top of the Porters Creek Clay in outcrop is a surface of considerable relief that formed by subaerial erosion during Paleocene time in southeastern Missouri (Farrar, 1935), western Tennessee (Parks, 1975), and southernmost Illinois (Willman and Frye, 1975). The unconformity is generally considered to divide the Midway and Wilcox Groups. However, in the outcrop belt of western Tennessee, some strata immediately overlying the unconformity were tentatively assigned to the "Betheden" and "Fearn Springs Formations" by Parks (1975); MacNeil (1951) considered both these units to be correlative with the uppermost part of the Midwayan Naheola Formation of the eastern Gulf Coast. Thus, the unconformity may be within the Midway Group. This unconformity has not been recognized in the subsurface of the northern Mississippi Embayment (Stearns, 1957) but may exist there even though it is not obvious from lithology or fossils. Depending on the age of the strata immediately overlying the unconformity in outcrop, the unconformity, if present in the subsurface, may be at the top or at the base of the interval from 1,377 to 1,339 ft in New Madrid well 1-X; this interval is probably late Midwayan in age and is tentatively assigned to the Old Breastworks Formation.

The absence of calcareous fossils and definitely indigenous dinoflagellates in samples from the Fort Pillow Sand (upper Paleocene) upward to the Jackson Formation (upper Eocene) suggests that this whole sequence was deposited in nonmarine environments. Little has been published about the location of the Sabinian (late Paleocene to early Eocene) shoreline; however, the Sabinian Stage, corresponding to all or part of the Wilcox Group, is well known as a mainly nonmarine unit over much of the Mississippi Embayment.

Stearns (1957) considered his "1,400-foot sand" (Fort Pillow Sand of Moore and Brown, 1969, and of this paper) to be a marine sand deposited during a transgression that covered the northern Mississippi Embayment including southeastern Missouri. No marine fossils were found within this interval in New Madrid well 1-X. However, in the Fort Pillow well in west-central Tennessee (Moore and Brown, 1969), some glauconite was found in scattered samples from the Old Breastworks Formation, Fort Pillow Sand, and Flour Island Formation. Trace amounts of silt-sized, bleached, pale-green glauconite were found in samples from the Wilcox Group in the New Madrid well, but the characteristics of the grains suggest that they are detrital rather than primary glauconite (Crone, 1981).

Stearns (1957) considered the contact between the Wilcox Group and his "500-foot sand" (contact between the Flour Island Formation and the Memphis Sand of Moore and Brown, 1969, and of this paper) to represent a major unconformity. The Memphis Sand probably correlates with the Gulf Coast sequence from the lower part to the middle part of the middle Eocene (Moore and Brown, 1969). Unfortunately, the cuttings from the Memphis Sand were too poor to enable a determination based on sporo-

morphs as to whether or not the lowest part of the middle Eocene (equivalent of the Tallahatta Formation of the eastern Gulf Coast) is represented in the New Madrid well; in short, we cannot determine biostratigraphically the extent of a possible unconformity between the Sabinian and the Claibornian in the New Madrid well. However, a distinct unconformity is present at this boundary in the eastern Gulf Coast (Huddlestun, Marsalis, and Pickering, 1974; Bybell, unpublished data) and in the outcrop belt in the northern Mississippi Embayment (Parks, 1975).

On the basis of dinoflagellates in samples from southwestern Kentucky, it has been suggested that various parts of the middle and upper Eocene in that area were probably deposited in brackish-water to marine environments (R. H. Tschudy *in* Finch and Minard, 1966, Swanson, 1970, Finch, 1971, and Lee, 1974). In contrast, none of the Eocene samples from the New Madrid test wells contains indigenous dinoflagellates. One of us (L.E.E.) also checked for dinoflagellates in four samples from the Jackson Formation (upper Eocene) exposed in the Mississippi River bluffs in the NW ¼ of Oakton 7.5′ quadrangle, Hickman County, Ky. (Lee, 1974), approximately 34 miles northeast of the New Madrid wells (fig. 1). All four samples contain abundant sporomorphs and many specimens of the freshwater alga *Pediastrum*. One of the samples lacks dinoflagellates altogether, two others contain rare, poorly preserved reworked Cretaceous forms, and the fourth sample contains the following assemblage:

Chatangiella spp.
Cyclonephelium sp.
Hystrichosphaeridium sp.
Isabelidinium cooksoniae (Alberti, 1959) Lentin & Williams, 1977
Odontochitina costata Alberti, 1961
Palaeohystrichophora infusorioides Deflandre, 1935
Small peridinioid forms

These specimens, also poorly preserved, are reworked from the Upper Cretaceous and suggest a possible age ranging from Coniacian to Campanian. In summary, the lack of indigenous dinoflagellates in all Eocene samples from the New Madrid test wells and in our upper Eocene outcrop samples from southwestern Kentucky, and the presence of reworked Cretaceous dinoflagellates in many of these samples, suggest that the dinoflagellates reported by Tschudy were reworked specimens and that the entire Eocene section in southeastern Missouri and southwestern Kentucky may have been deposited in nonmarine environments.

The maximum northward extent of the middle Eocene shoreline in the Mississippi Embayment has not been established, but it is well known that this shoreline oscillated widely during several transgressions and regressions (Fisher, 1964). Elsik (1974, Textfig. 6) suggested that the middle Eocene shoreline extended only as far north as central Arkansas and northern Mississippi. In the northern part of the Mississippi Embayment, marine Jacksonian invertebrate and vertebrate fossils have been reported from southeastern and east-central Arkansas (Palmer, 1939; Wilbert, 1953) and from southwestern Tennessee (H. N. Fisk *in* Wilbert, 1953, p. 103; F. C. Whitmore, Jr., *in* Moore and Brown, 1969). Thus, present evidence suggests that the maximum northward extent of the late Eocene shoreline was in west-central or northwestern Tennessee, just south of the New Madrid wells and of the southwestern Kentucky outcrops.

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PALEONTOLOGICAL NOTE

BULIMINELLA MORGANI ANDERSEN, 1961 AND *BULIMINELLA MISSISSIPPENSIS* SEIGLIE, 1969 — A CRITICAL APPRAISAL

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Phleger and Parker (1951) described a small buliminellid from Station 212 (*Atlantis* cruise, 1947), located at Lat. 27°50.5′N., Long. 96°19′ W., in the Northwest Gulf of Mexico at a depth of 50 m. These authors compared and related this modern form to *Buliminella bassendorfensis* Cushman and Parker, 1937, which had been described from the Oregon Oligocene. This assignment was accepted by Gulf Coast micropaleontologists for a number of years (*e.g.*, Lankford, 1959). *Buliminella* cf. *bassendorfensis (sensu* Phleger and Parker, 1951) was placed in the synonomy of a new species *Buliminella morgani* by Andersen, who provided a definitive description and illustration of the new taxon (1961, p. 87, pl. 19, fig. 10). The types for this species were obtained from Mudlumps SP-1 and SP-3 at the mouth of Southwest Pass of the Mississippi River delta. This species name has been, and is presently, accepted by workers in this region (*e.g.*, Poag, 1981; Finger, 1982). It is further cited in the massive data compilation presented by Culver and Buzas (1981).

In his taxonomic notes on the genera *Buliminella* and *Bulimina*, Seiglie (1969) established the species *Buliminella mississippensis* for forms obtained from a core taken in 106 meters of water in the northeast Gulf of Mexico at Lat. 29°04.5N, Long. 88°52′W. Seiglie (1969, p. 101) placed *Buliminella* sp. cf. *B. bassendorfensis (sensu* Phleger and Parker, 1951) in the synonomy of this new species. The morphoseries presented by Seiglie (*ibid.*, pl. 6, figs. 1-11, pl. 7, figs. 1-10) clearly includes the form *B.* cf. *bassendorfensis* of Phleger and Parker, 1951, and *B. morgani* Andersen, 1961.

Buliminella mississippensis Seiglie, 1969, is a junior synonym of *Buliminella morgani* Andersen, 1961, and in accordance with ICZN Articles 23 and 24 it is recommended that the name *B. mississippensis* Seiglie, 1969, be suppressed in order to ensure stability and universality of nomenclature.

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BIOSTRATIGRAPHIC POTENTIAL OF THE CRYPTODONT BIVALVE *BUCHIOLA RETROSTRIATA* FROM UPPER DEVONIAN SHALE, SOUTHWESTERN VIRGINIA

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ABSTRACT

Buchiola retrostriata (von Buch), a former inhabitant of muddy deep-sea substrata, can be used to identify lower Upper Devonian shale (about middle Finger Lakes to basal Cohocton) in Virginia. This distinctive and fairly abundant cryptodont clam has potential as a zonal guide fossil for rocks characterized by what has been traditionally termed the "Naples fauna" in the Appalachian Basin.

At a time when Devonian shales in the Appalachian Basin are being explored as possible new sources of natural gas, and are being sampled and mapped with increasing frequency, it is clearly advantageous to the field geologist to be able to distinguish these shales from lithologically similar units at different stratigraphic levels and to recognize stratigraphic position of shales within the Devonian. Based on our experiences in southwestern Virginia, *Buchiola retrostriata* can be used as both a guide to the lower Upper Devonian in the region and as a means of distinguishing the Brallier Formation from younger shaly units occurring in discontinuous outcrops.

In the summer of 1980, the authors were instructors at Virginia Polytechnic Institute's geology field school in southwestern Virginia. One of the projects assigned to our students involved mapping rock units in a structurally complex area north of Nebo in northeastern Smyth County (Fig. 1). In the mapping area, Cambro-Ordovician dolomite and limestone override a thick sequence of shale along the Saltville Thrust Fault. After an initial examination of individual rock units, a question arose as to the identity and age of the shale unit in the footwall block. The unit is composed of sparsely fossiliferous, greenish-gray shale, with dark gray shale and grayish-green sandstone interbeds. Sandstone layers contain macerated, carbonized plant fragments. Rare invertebrate animal remains are localized on a few bedding planes within the shale. The entire unit is folded, broken, and geometrically distorted due to flowage beneath the sole of the fault.

The shale unit occurs in a part of Virginia that has not been mapped in detail. Although similar in general appearance to the Upper Devonian Brallier Formation, we initially thought that the shale could be a "Chemung" (Greenland Gap Group) equivalent based on abundance of green shale, or part of the Lower Mississippian Price Formation based on presence of sandstone containing plant fragments and the dark gray shale beds. We identified the shale unit as Brallier by collecting specimens of *B. retrostriata,* a cryptodont bivalve limited to rocks of Late Devonian age (Cox *et al.*, 1969, p. N244; Shimer and

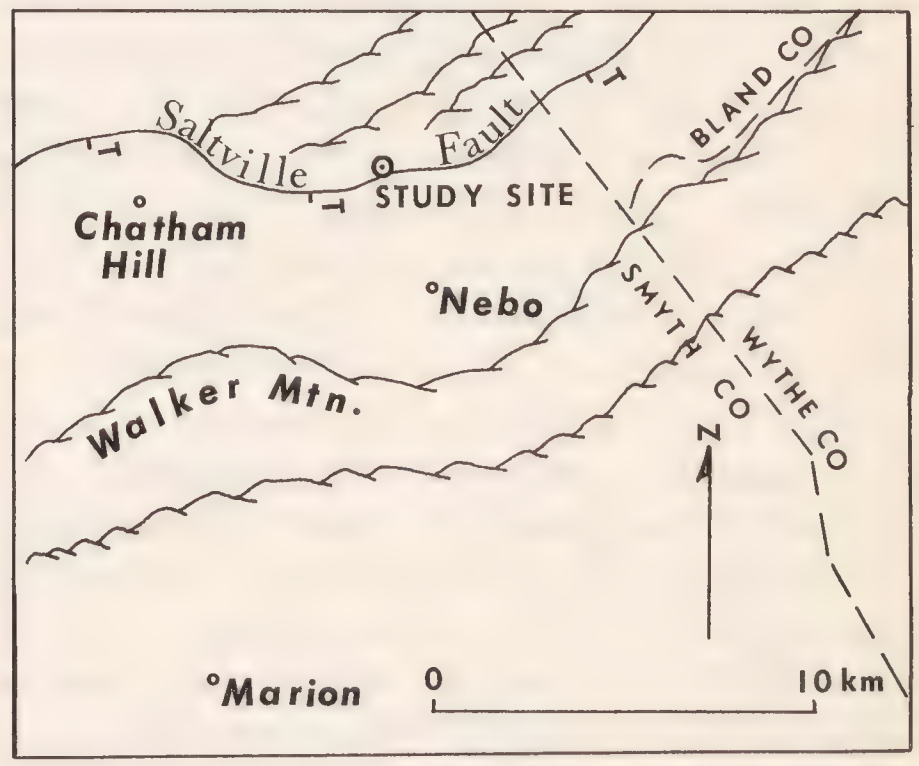

Figure 1. Location map showing study site where we first recognized the biostratigraphic value of *Buchiola retrostriata.*

Shrock, 1944, p. 373) and previously described as occurring only in the Millboro Shale and Brallier Formation in Virginia (Butts, 1940, pp. 310, 319), from outcrops along Smyth County Road 622.

Subclass CRYPTODONTA Neumayr, 1884
Order PRAECARDIOIDA Newell, 1965
Family PRAECARDIIDAE Hornes, 1884
Genus BUCHIOLA Barrande, 1881

BUCHIOLA RETROSTRIATA
(von Buch, 1832)
Fig. 2

*Diagnosis:*Shell small, thin, approximately equivalve with prosogyrate beaks; valves hemiovoid, slightly inflated and elongate; cardinal area broad and straight with a few taxondont-like denticulations in some specimens located below weakly developed beaks; twelve to fourteen wide, flat plications with elevated edges radiating from the beaks, each plication crossed by curved, ventrally concave corrugations; in mature areas of shell, groove between plications divided by a low, narrow radial ridge.

Discussion: The Brallier Formation was deposited on the outer parts of a submarine fan located seaward of the extensive Catskill delta system (see Avary and Dennison, 1980; McIver, 1970). Shale layers in the Brallier are interpreted as hemipelagic deposits that accumulated between pulses of turbidity current sedimentation (represented by sandstone interbeds).

Two general modes of life seem possible for *B. retrostriata*. Occurrence in association with a sparse fossil assemblage containing pelagic cephalopods and within a deep-water shale deposit suggests an epiplanktic mode of life, perhaps floating in the upper part of the water column attached to algae or other debris (Goldring, 1978, Fig. 38; Thayer, 1974, Fig. 18A). However, we favor the interpretation that *B. retrostriata* was an epifaunal or semi-infaunal benthic organism, which lived in small groups on or in the muddy submarine fan surface. Evidence for this comes from the following morpho-functional attributes: 1) thin shells (serving to diminish whole animal density); 2) small size (creating a high surface area/volume ratio); and 3) broad shell plications (enhancing high surface area/volume ratio). These characteristics of the shell could have promoted buoyancy in soft sediment and probably allowed successful occupation of muddy, deep-water substrata (see Stanley, 1970, p. 83).

Biostratigraphic potential: Buchiola retrostriata is one of the more abundant and easily identified components of the so-called "Naples fauna" in the Appalachian Basin (Butts, 1940, p. 316; Prosser and Swartz, 1913, p. 413; Clarke and Swartz, 1913, p. 614). The Naples fauna in Virginia also contains comparatively rare *Probeloceras lutheri* Clarke, an ammonoid whose stratigraphic occurrence defines a range zone in the upper half of the Finger Lakes Stage of the Senecan Series (Fig. 3). Other components are small bivalves (*Honeoyea* sp., *Ontaria* spp., *Paracardium doris* Hall), small cephalopods (*Bactrites* spp.), and a possible pteropod (*Styliolina fissurella* (Hall). Large brachiopods are conspicuously absent. Lists and illustrations of Naples taxa can be found in Butts (1940, 1941).

This unique assemblage ranges from about the upper half of the Millboro Shale

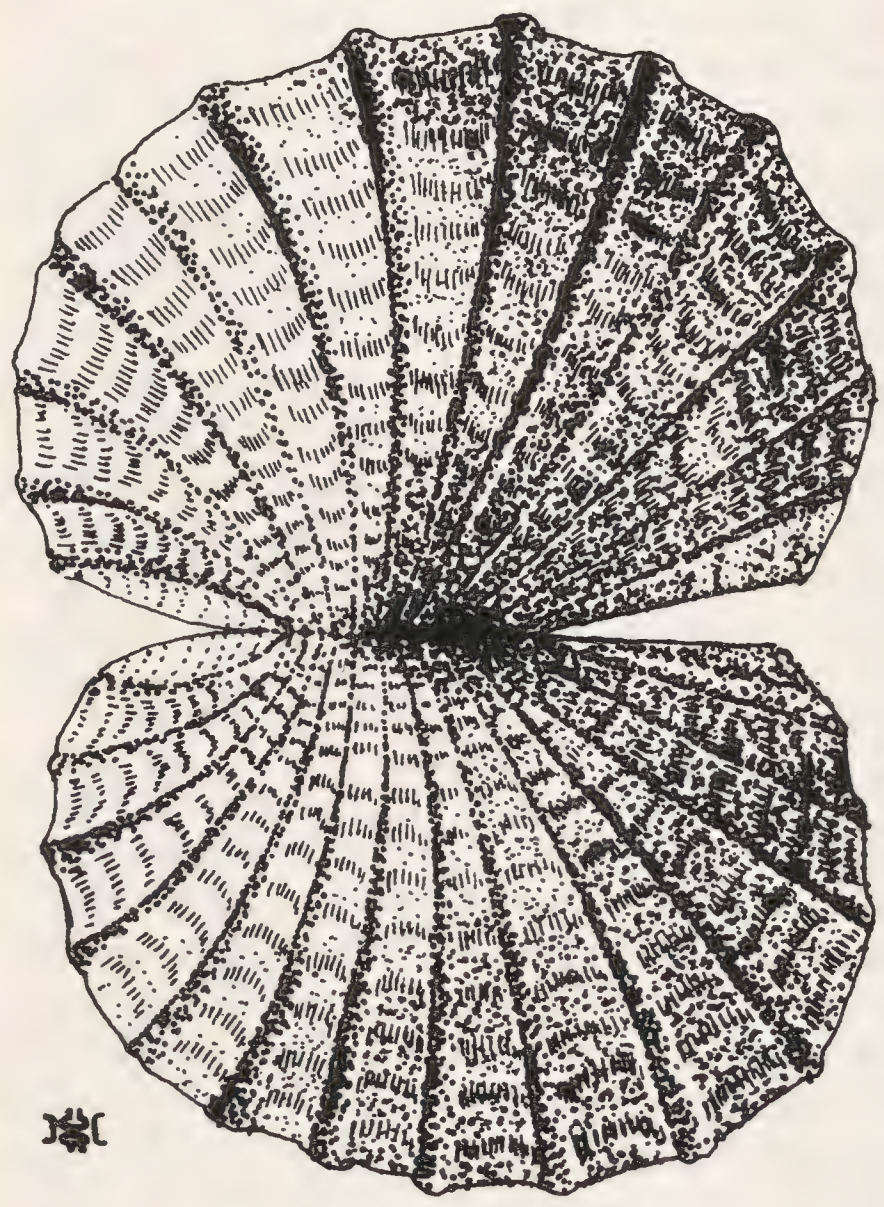

Figure 2. Restoration of *Buchiola retrostriata* showing valves conjoined. External view, approximately × 12. (Sketch by Harris.)

(middle Finger Lakes) through the Brallier (upper Finger Lakes to basal Cohocton) defining an assemblage zone in Virginia, which is equivalent to the "Naples horizon" and "Brallier Shale" as defined on paleontologic grounds by Butts (1940, p. 308-320).

In the absence of a diverse and abundant fauna, *B. retrostriata* is a characteristic fossil of the upper Millboro and the Brallier. It occurs in greater numbers than *P. lutheri* (we collected 26 external and internal molds of *B. retrostriata* and only one of *P. lutheri* in several hours of searching), and its size (3 to 10 mm in largest dimension for molds collected) and distinctive surface ornamentation make it easy to identify even when incomplete molds are found. *Buchiola retrostriata* is minute and distinctive enough to be identified in chips or cores collected from the subsurface, and has obvious potential as a zonal guide fossil (see Krumbein and Sloss, 1963, p. 357).

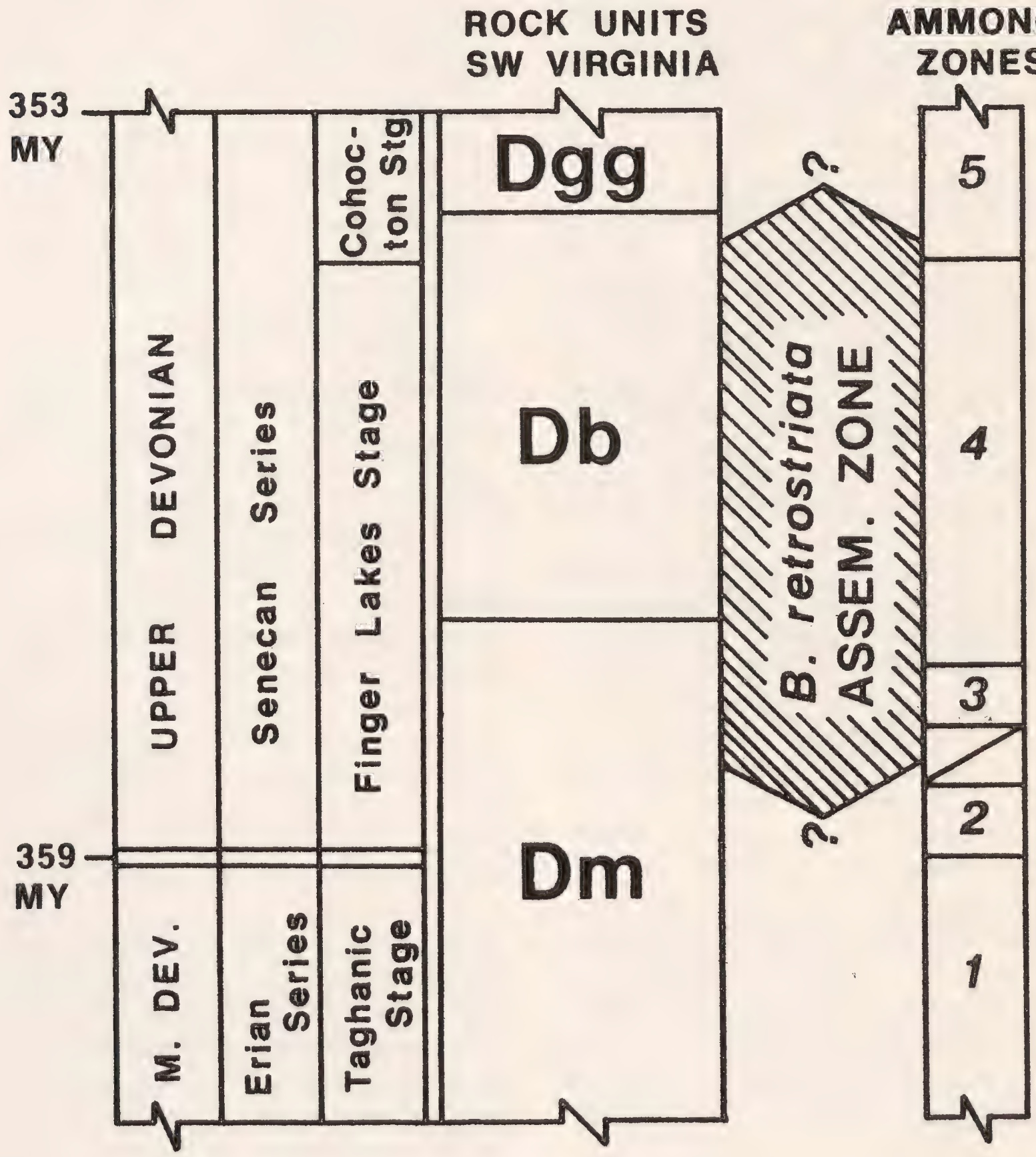

Figure 3. Divisions of the Upper Devonian and position of the *Buchiola retrostriata* assemblage zone. Rock units: Dm, Millboro Shale; Db, Brallier Formation; Dgg, Greenland Gap Group equivalents. Ammonoid zones: 1, *Pharciceras amplexum;* 2, *Ponticeras perlatum;* 3, *Manticoceras simulator;* 4, *Probeloceras lutheri;* 5, *Manticoceras rhynchostoma.* (Divisions and absolute ages based on Avary and Dennison, 1980, Fig. 3; ammonoid zones from Norris, 1979, Fig. 6).

We recommend that the rocks characterized by the Naples fauna in Virginia be regarded as the *B. retrostriata* assemblage zone (Fig. 3), with *B. retrostriata* serving as a zonal guide fossil because of its fairly short range, numerical abundance compared to other co-occurring taxa, and its distinctive appearance. *Buchiola retrostriata* could become a useful tool for field geologists in recognizing lower Upper Devonian shale occurring in isolated outcrops, and possibly could be used in subsurface exploration because only fragments of external molds are required for identification of the species.

We thank Dr. A. L. McAlester for useful suggestions concerning ecology of *Buchiola*, and we are grateful for critical comments of an anonymous reviewer.

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October 28, 1982

REVIEW

METAMORPHIC PETROLOGY: Mineralogical, Field, and Tectonic Aspects, by Francis J. Turner. Published by Hemisphere Publishing Corporation, Washington, New York, and London, Second Edition, 1981, xvii + 524 pp., illus., $28.50

In this second edition, the approach, purpose, and scope of the work remains essentially the same as in the first edition, emphasizing Eskola's facies concept and synthesis of metamorphic facies. Through this most sensible approach, the mineralogical data and field aspects of metamorphic petrology are most readily perceived and understood by the reader. It has long been recognized that a gradual transition from seimentary rocks to rocks with mineralogical compositions and structures resulting from processes of transformations (or, *metamorphism*) exists in many diverse regions on all continents. It is recognized that the proper study of geological processes is accomplished in the field in the examination of specific exposures. Thus, Professor Turner has made extensive use of case histories to explicate his treatment and descriptions of metamorphic processes. The text is forthright, well organized, and quite readable. This new edition is highly recommended.

—H.C.S.

NOTES ON THE FAUNA OF THE CHIPOLA FORMATION — XXV: ON THE OCCURRENCE OF THE GENUS *ROTHPLETZIA* SIMONELLI (MOLLUSCA: GASTROPODA)

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One of the unexpected discoveries in the fauna of the Burdigalian (late lower Miocene) Chipola Formation of Calhoun County, Florida, is the occurrence of a species of the hipponicid genus *Rothpleztia* Simonelli, 1890, originally described as *R. rudista* on the basis of specimens collected from Miocene (presumably Vindabonian) deposits on Gran Canaria Island. Specimens that seem certainly to be referrable to the same genus, collected from the southern part of the island of Trinidad, were subsequently described by Hodson and Harris in 1931 as representing "an Oligocene Rudistid" for which they proposed the name *Neomonopleura weidenmayeri*. Rutsch (1934) later synonymized *Neomonopleura* with *Rothpletzia* and reported the presence of the Trinidad form in the Antigua Limestone on the island of Antigua.

The original specimens of *"Neomonopleura" weidenmayeri* were collected from the Morne Diablo Quarry, No. 1, in the southern part of Trinidad from strata reported as of middle Oligocene age (Hodson and Harris, 1931, p. 136). Kugler (1953, p. 42) said that the Morne Diablo 'Marac,' in which the quarry is located, consists of upper Oligocene limestone, but subsequently stated (p. 50) that these limestones are in the *fohsi* and *insueta* planktonic foraminiferal zones. These zones are now considered as being uppermost lower Miocene and early middle Miocene (Blow, 1969). The Chipola Formation is referred to the *Globigerinatella insueta* zone, N7 of Blow, although that deep-water species is not actually present (Akers, 1972, p. 8).

The similarity to the rudistid bivalves, expressed in the specific name given to the type species of *Rothpletzia* and in the taxonomic assignment of the Trinidad form appears to be the result of an unusual growth shape caused by the ecologic environment in which these forms developed. Many of the species of the hipponicid genera *Hipponix* and *Malluvium,* as well as *Rothpletzia* secrete a calcareous "Stützklappe" or supporting plate that, as Keen (1971, p. 451) states, is "in effect an attached operculum . . . on which the animal rests." In all known occurrences the specimens of *Rothpletzia* are associated with algal limestones, mainly *Lithothamnion*. The excellent preservation of the initial coiled portion of the basal plate of the Chipola specimens as well as the ornamentation of its surface clearly indicates that it was not cemented to a substratum but rather was apparently nestled in the algal mat; the upward growth of the margins may well have been a function of the necessity of keeping the aperture above the level of the increasingly thick surrounding algae. A cross section of the "Stützklappe" of one of the specimens figured by Simonelli (1890, pl. 36, fig. 6d) shows transverse partitions, termed "septen" by the author, indicating that the animal found it necessary to move upward in the shell as the algal growth forced increase in height. The Chipola specimens are much less vertically extended than are those in which these structures occur; apparently the algal growth was not sufficient to require their development.

Family HIPPONICIDAE Troschel, 1861
Genus ROTHPLETZIA Simonelli, 1890

Rothpletzia SIMONELLI *in* ROTHPLETZ and SIMONELLI, 1890, Zeitschr. Deutsch. Geol. Gesellsch., v. 42, p. 711. Type species (by monotypy): *Rothpletzia rudista* Simonelli (*sup. cit.*, p. 711, pl. 36, figs. 6, 6a-d); Miocene, Gran Canaria Island.

Neomonopleura HODSON and HARRIS, 1931, Bulls. Amer. Paleontology, v. 16, no. 61, p. 135. Type species (original designation): *Neomonopleura weidenmayeri* Hodson and Harris (*sup. cit.*, p. 135, pl. 1, figs. 1-3; pl. 2, figs. 1, 2) "Oligocene" (?lower Miocene), Trinidad.

ROTHPLETZIA FLORIDANA H. E. Vokes, n. sp.

Text figures 1 - 3

Description: The shell is relatively small and composed of two units. There is a "lower valve" or "attachment plate" that is cup-shaped with a flattened basal disc and upwardly arched sides leading to a broadly ovate "aperture;" sides of the shell in this area are of unequal length, the "posterior," which rises more or less directly above the apical end of the basal disc, is short and straight to slightly concave in profile; that on the opposite, or "anterior," side is broadly convex and in all specimens is at least twice the length of

the other. The "upper valve" is of typically hipponicid cup-shaped form. The apices of both the upper and lower units have a coiled protoconch of two smooth whorls succeeded by a teleoconch ornamented with submicroscopically fine, rounded radial ribbing; the number of ribs is increased by intercalation until they number approximately twenty-five to the millimeter on the upper edge of the anterior side of the holotype specimen; these ribs tend to be interrupted by irregularly spaced, moderately strong concentric growth lamellae. Interior of the "valves" with typically hipponicid horseshoe-shaped muscle scars adjacent to the aperture, that in the "lower valve" located around the shorter side, that on the upper one apparently above the apical end.

Holotype: USNM 340288; greatest length 13.2 mm; height of posterior side* 4.1 mm; height of anterior side* 10.6 mm; aperture length 11.7 mm; aperture width 10.55 mm. Locality TU 1048.

Paratype A: USNM 340289; greatest length 9.5 mm; height of posterior side* 3.3 mm; height of anterior side* 5.7 mm; aperture length 8.2 mm; aperture width 7.1 mm. Locality TU 1196.

Paratype B: USNM 340290; length, slightly incomplete, 7.6 mm; width 7.9 mm; height 2.0 mm. Locality TU 1048.

Type locality: TU 1048, Farley Creek, south bank, about 0.8 mile east of bridge of Florida Highway 275 (NE ¼ Sec. 21, T1N, R9W), Calhoun County, Florida.

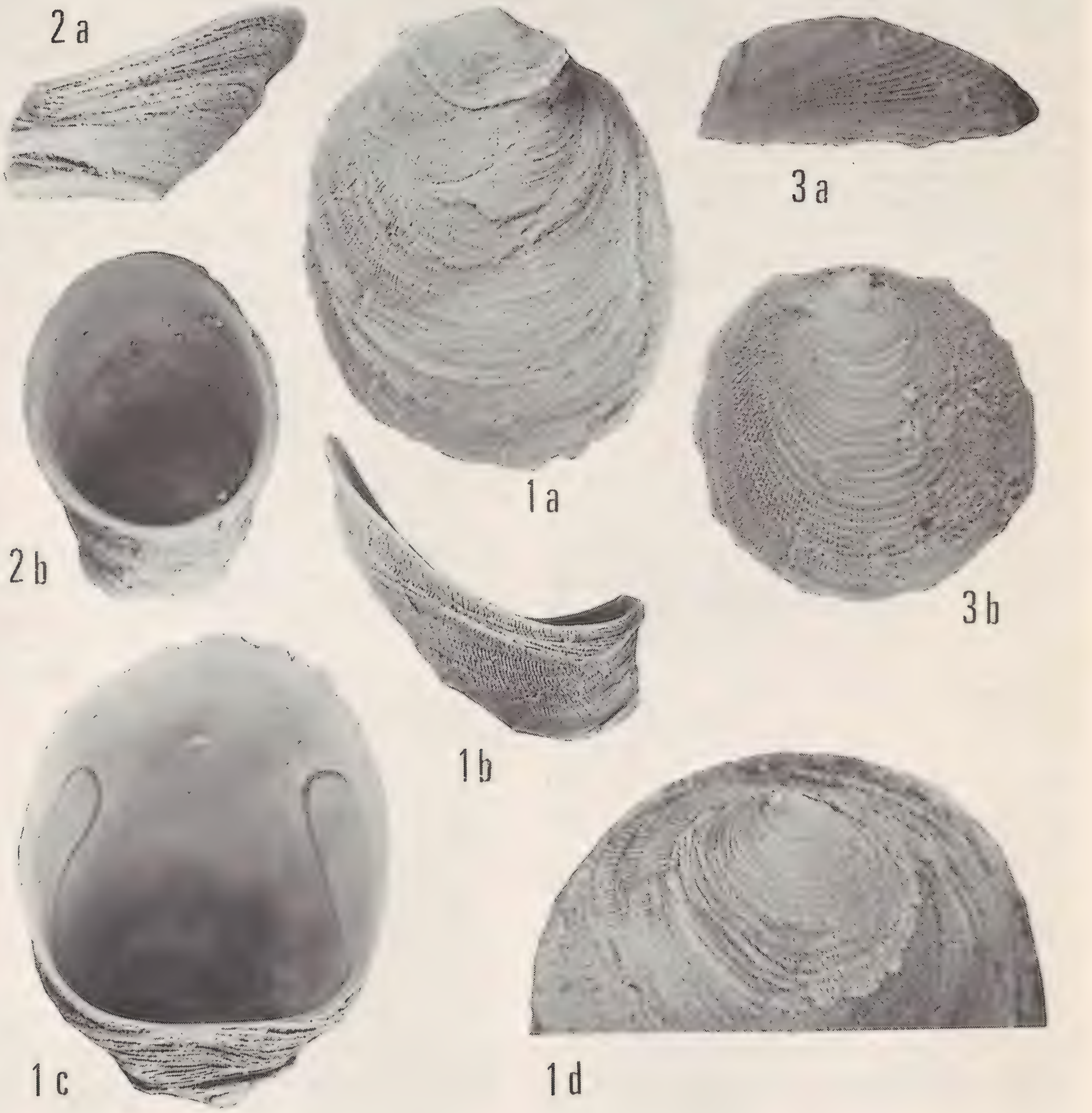
Remarks: None of the specimens from the Chipola Formation attain the elongated rudistid shape of the "lower valves" such as is present in both the type of the genus and the Trinidad species, and none show the transverse "septen" shown in the original illustrations of *R. rudista* (Rothpletz and Simonelli, 1890, pl. 36, fig. 6d); the writer is inclined to attribute this difference to a less rapidly growing algal mat in the, presumably, slightly cooler waters present at the Chipola localities. The specimens of *R. floridana* are also considerably smaller than are those of the other two species. Simonelli did not cite the dimensions of his form, but it is to be noted that when illustrations of other species were enlarged they were accompanied by an adjacent line indicating their height or length; such indications are absent from those of *Rothpletzia rudista*, and when they were subsequently reproduced by Wenz (1944, p. 887, fig. 2608) the dimensions were shown as "1/1." Measurement of the original figures reveals a total length of 36.2 mm for the largest specimen, a height of 24.2 and a width of 20.2 mm for a smaller one with an attached "upper valve" that, separately figured, shows a greatest length of 20.8 and a width of 17.1 mm. These dimensions indicate that species attained almost three times the size of the present form. The figured types of *"Neomonopleura" weidenmayeri* Hodson and Harris are somewhat larger than those of *R. rudista,* the holotype, an internal cast that includes both "valves," is stated to have a length "from beak to beak" of 34 mm, and the paratypes to have "lengths" of 48 to 50 mm, and "greatest diameters" of 26 to 30 mm.

One striking difference between the Chipola and the type species appears to lie in the position of the muscle scars. Simonelli states (freely translated, italics mine): "Near the aperture and *always on the convex side of the shell curvature* lies a large horseshoe-shaped muscle imprint;" in all of the specimens of *R. floridana* the scar is situated adjacent to the shorter, straight to concave side with the broader convex side apparently being the apertural one. The ornamentation on the Chipola specimens appears to be very similar to that on the "upper valve" of *R. rudista,* described as consisting of "weak, densely crowded, erect radial ribs that are crossed near the lip by finer concentric striations." One of the paratypes of *R. weidenmayeri* (Hodson and Harris, 1931, pl. 2, fig. 2) has a portion of the outer surface preserved on the "lower valve," which is also very like that on *floridana* though somewhat coarser on the larger shell. Simonelli, however, described the exterior of the "lower valves" of *R. rudista* as being formed of "superimposed scaly lamellae," a feature that may reflect the erosion of the finer ornament by the *Lithothamnion* algal masses, rather than the original condition.

Rothpletzia floridana is represented in the Tulane University collections from the Chipola Formation by one "upper" and five "lower valves." All are from localities near the basal part of the formation on the upper reaches of Farley Creek, a tributary entering the Chipola River from the east. The

*Assuming the basal disc as a flattened basal surface.

sediments here are primarily lime sands derived in part from the erosion of the underlying Chattahootchee Limestone; there are also occasional quartzite pebbles that apparently have been transported from much older sources to the north. The fauna at these localities is exceedingly rich with many species of Mollusca, including abundant shells of true *Hipponix*, plus solitary and colonial corals, tube worms, and calcareous algae fragments. Similar conditions and faunas occur at many other Chipola



Text figure 1, *Rothpletzia floridana* n. sp. 1-Holotype, USNM 340288, lower "valve;" a) basal view, × 4; b) lateral view, × 4; c) dorsal view showing muscle scars, × 4; d) view of flattened "attachment" area showing ornamentation and nuclear whorls, × 6. 2-Paratype, USNM 340289, lower "valve;" a) lateral view, × 4; b) dorsal view, × 4. 3-Paratype, USNM 340290, upper "valve;" a) lateral view, × 6; b) dorsal view showing ornamentation and nuclear whorls, × 6.

localities and it is difficult to determine those factors that seem to have resulted in the presence of *Rothpletzia* only at these sites.

LOCALITY DATA

The specimens of *Rothpletzia* were collected from the following Tulane University localities in the Chipola Formation, as exposed in Calhoun County, Florida:

823. Farley Creek, south bank about 2000 feet east of bridge on Florida Highway 275 (SE ¼ Sec. 21, T1N, R9W).
1048. Farley Creek, south bank about 0.6 mile east of bridge on Florida Highway 275 (SW ¼ NE ¼ Sec. 21, T1N, R9W).
1049. Farley Creek, south bank about 1.0 mile east of bridge on Florida Highway 275 (NE ¼ NE ¼ Sec. 21, T1N, R9W).
1196. Farley Creek, north bank about 0.65 mile east of bridge on Florida Highway 275 (SW ¼ NE ¼ Sec. 21, T1N, R9W).

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October 28, 1982

REVIEWS

THE GEOLOGICAL SCIENCES IN THE ANTEBELLUM SOUTH, edited by James X. Corgan. Published by The University of Alabama Press, University, Alabama, 1982, v + 195 pp., illustrated, indexed, $17.50

This symposium contains nine papers by ten contributors offering insight into the southern geological work (1796-1860) of thirteen scientists, all of which had significant impact on intellectual and scientific development in the United States. Among these are Charles Lyell, already a celebrated scientist when he first visited the South in 1841; Gerard Troost and W. B. Rogers from early state-supported geological surveys; and Ebenezer Emmons, author of the ill-fated Taconic System. All did significant work in the southern states; this useful volume illustrates their impact on American science.

MARINE GEOLOGY, by James P. Kennett. Published by Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1982, xv + 813 pp., Illustrated, index, $35.00

This volume fulfills the need for a synthesis of marine geology, incorporating the enormous advances in this field during the last two decades. It is comprehensive and should prove most useful as a beginning text in this subject as well as a reference handbook for the working geologist and oceanographer.

Following the brief introduction and history of marine geology, the book comprises four sections: The Structural and Oceanographic Setting, The Ocean Margins, Oceanic Sediments and Microfossils, and Ocean History. Each section is well organized and clearly written; the book is highly recommended.

—H.C.S.

NOTES ON THE FAUNA OF THE CHIPOLA FORMATION — XXVI: A NEW SPECIES OF *TRACHYCARDIUM* FROM TENMILE CREEK

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In 1977 the writer published a study on the Cardiidae of the Chipola Formation in which 16 species were identified in collections that included 40,342 specimens. It was with considerable surprise, therefore, that recently a valve of what is clearly a new species of *Trachycardium* was collected by George Mollyn, a Tulane University graduate student, from locality TU 951 on Tenmile Creek, Calhoun County, Florida.

Genus TRACHYCARDIUM Mörch, 1853

Trachycardium MÖRCH, 1853, Catalogus Conchyliorum . . . Comes de Yoldi, Fasc. 2, p. 34. Type species, by subsequent designation, von Martens, 1870: *Cardium isocardia* Linnaeus, 1758. Recent; West Indies from Jamaica to Trinidad, the Caribbean coast of northern South and Central America and the southern Gulf of Mexico, around the Yucatan Peninsula and westward at least as far as Isla Carmen, Mexico.

As is the case with the other Chipola species assigned to the genus *Trachycardium,* the present form lacks the characteristic ornament of round-topped imbricating scales that are strongly developed over all, or almost all, of the surfaces of the costae on the median part of the valves. The nature of the ornament on the ribs on the median part of the shell is somewhat similar to that present on species referred to *Dallocardia* Stewart, 1930, but the shape of the shell is very different and the exceedingly narrow, straight-sided linear ribs, with flattened upper surface overhanging on both sides, plus the narrowly lineate interspaces, are of completely different aspect than the less numerous, broader and round-topped ribs of that subgenus. Accordingly the present species is assigned to *Trachycardium* sensu lato.

TRACHYCARDIUM MOLLYNI
H. E. Vokes, n.sp.

Text figure 1

Description: Shell of medium size, subequilateral, subovate with anterior, antero-ventral, and ventral margins broadly and almost equally rounded, more sharply rounded postero-ventrally into an almost straight, but slightly convex posterior end that passes into the dorsal margin in an arc essentially equal to that on the postero-ventral margin; umbone narrow, moderately high, not strongly inflated; ornamentation of 60 radial ribs, the anterior five or six being essentially sloping lamellae, overhanging the interspaces posteriorly, but sloping gently into them anteriorly; these ribs bearing strong, transversely narrowed nodes; the ribs immediately posterior with similar surficial nodes but becoming narrower and more erect with a vertical posterior side and a rounded, semi-erect anterior one; toward the umbonal end of the tenth costa numerous small spines appearing on the posterior side of the overhanging rib top; from this point on the transverse nodes progressively disappearing ventrally until finally absent on the twenty-first and subsequent ones; the small marginal spines present on all up to and including the fortieth one, interspaces in this area narrow and linear, the ribs very narrow below the top surface, which tends to be flattened and projecting on both anterior and posterior sides, the whole being suggestive of the transverse section through a railroad rail; ribs on the posterior slope of the valve beginning as a relatively narrow structure marked by a median groove that separates a smooth anterior segment from a posterior one crossed by sharp, obliquely transverse nodes; these ribs becoming progressively lower and broader, although the median groove continues essentially as strong, and the interspaces progressively shallower until, on about the forty-fifth or forty-sixth rib, the obliquely spined segment assumes the appearance of being on the anterior side of the structure, with the median groove so much more pronounced than the interspace that it appears to represent the latter: on last two or three ribs the former anterior segment reduced to a low broadly rounded area between the segments on which the oblique spinose lamellae have become increasing numerous, higher and more prominent. Hinge structure typical of the genus *Trachycardium;* internal margins deeply serrate, muscle scars typical, not incised.

Holotype: USNM 340287; height 47.0 mm, length 37.3 mm, diameter (right valve) 16.7 mm.

Type locality: TU 951, Tenmile Creek, south bank about 1.5 miles west-northwest of mouth of creek at Bailey's Ferry (SE ¼ Sec. 12, T1N, R10W), Calhoun County, Florida.

Remarks: Trachycardium mollyni, n. sp., is distinguished from all other described East Coast Tertiary and Recent species by the number of its radial costae. The majority of the species referred to this generic

group tend to have between 35 and 40 ribs, a few attain up to 50. The only exception, of which the writer is aware, is *T. (Dallocardia) dominicense* (Gabb) (1873, p. 250), from the Burdigalian Baitoa Formation of the Dominican Republic, originally described as having about 60 ribs; seven specimens in a collection presently being studied have 51 to 58 ribs, all being round-topped with narrow relatively shallow interspaces, and having a wholly different type of surficial ornament. *Cardium (Trachycardium) gatunense* Toula, 1901 (p. 720, pl. 27, fig. 4; pl. 28, fig. 18; *non Cardium (Fragum) gatunense* Dall, 1900, p. 1100) appears to be a synonym of *T. dominicense*.

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October 28, 1982

Text figure 1, *Trachycardium mollyni* n. sp., Holotype, USNM 340287. A) Right valve, × 1⅓; B) View of surface ornament on posterior segment of valve, × 2; C) View of surface ornament on anterior area, × 2.

THE GENUS *HARPA* LAMARCK (MOLLUSCA: GASTROPODA) IN NORTHERN SOUTH AMERICA

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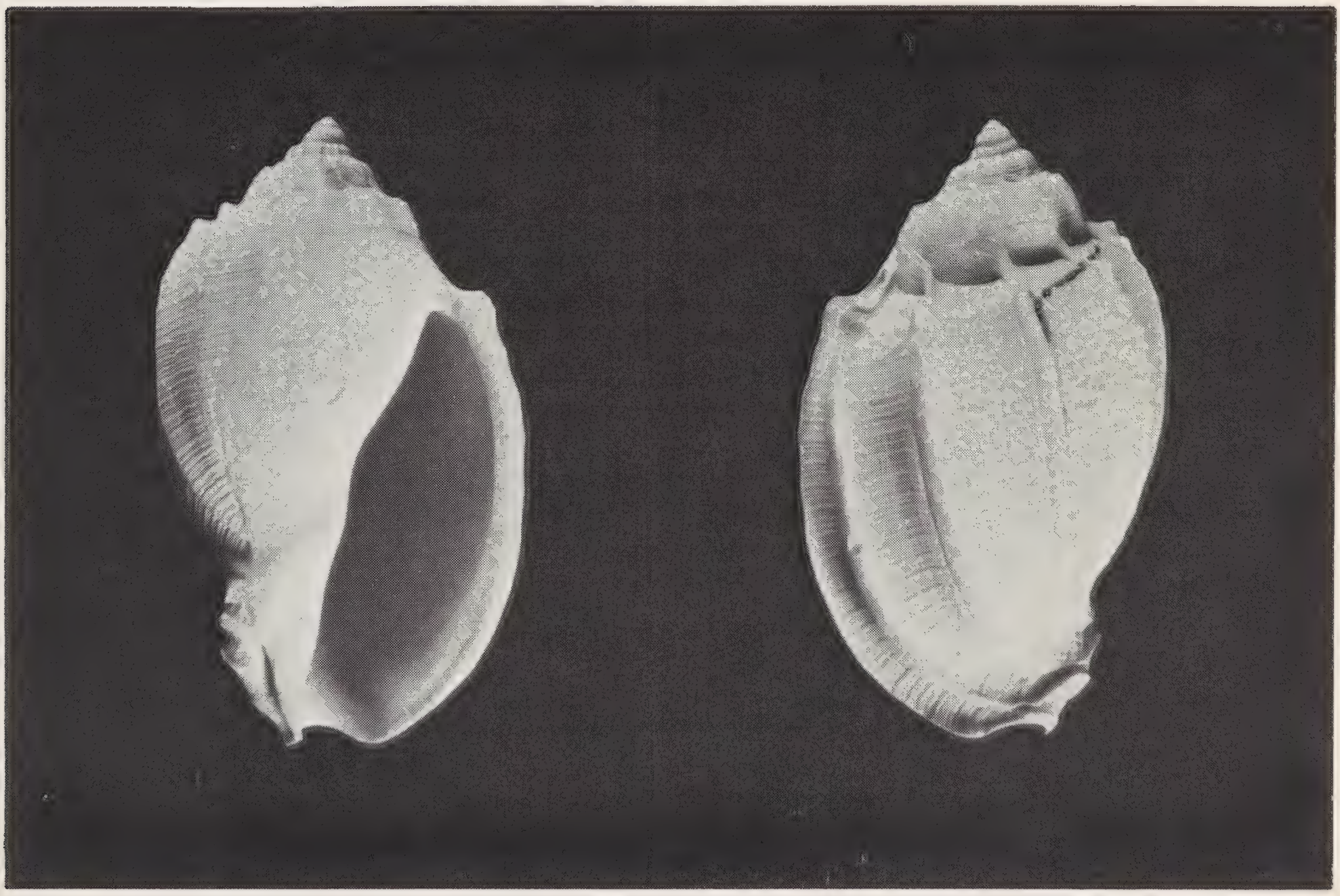
In a recent number of this journal the occurrence of *Harpa americana* Pilsbry, 1922, in the Quebrada Camarones section of northwest Ecuador, was divulged by Pitt (1981, p. 155). It was noted that this extended the range of this taxon into the Pacific Region, previous reportings being from the Mio-Pliocene of the Caribbean only: from the Dominican Republic (type locality) by Gabb (1873, p. 214) as *H. rosea* Lamarck, 1816 (*non* Lamarck) being renamed later by Pilsbry (1922, p. 337), and from Veracruz, Mexico, by Perrilliat Montoya (1960, p. 24). Not mentioned, however, was the reporting by Gibson-Smith and Gibson-Smith (1979, p. 22) of the presence of *H.* sp. cf. *americana* in the early Miocene (Burdigalian) Cantaure Formation of the Paraguaná Peninsula, Venezuela (Figs. 1-3).

Whilst very similar to *H. americana,* the four Cantaure specimens suggest minor differences. The latter form has a slightly inclined protoconch of 3½ to 3¾ whorls, with a total of seven to eight whorls at shell heights between 32.8 and 41.0 mm with corresponding diameters between 19.7 and 26.8 mm, the average H/D being 1.64. *Harpa americana* has a three whorl protoconch and only six whorls at a height of 41.0 mm. It should be noted that the dimensions of the holotype given by Pilsbry (1922, p. 337, pl. 23, fig. 13) are: height 33.3 mm, diameter 28.6 mm, H/D being 1.16; they are clearly in error. The figure is drawn to natural size and measures height 41 mm, diameter 24 mm, H/D being a more reasonable 1.7. Hence, part of our hesitation in assigning the Venezuelan material unequivocably to *H. americana.* Another consideration concerned the prov-



Text figures 1,2. *Harpa myrmia* Olsson
Height 32.8 mm, diameter 19.7 mm.
Locality: Cantaure Formation, Paraguaná Peninsula, Venezuela.

enance of the two forms: *H. americana* pertains to the West Indian and Mexican subprovince(s) of the Caribbean Miocene whereas the Venezuelan form comes from the northern South American subprovince. These subprovinces, based on endemic genera and subgenera, were defined by Woodring (1974, p. 209) and have been recognized more recently by several authors as persisting to the present day. The possibility, therefore, that two lineages exist could not be ignored.

The ancestor of the Ecuadorian and Venezuelan form(s) is *H. myrmia* Olsson, 1931, from the Oligocene Chira Formation of Peru, a form which the author did not differentiate from *H. americana*. Either this was due to an oversight, which is unlikely, or, perhaps, the heavy ribs of the last half-turn of the body-whorl, not reported as present in *H. americana,* were considered distinction enough without further comment or, maybe, the misquoted dimensions played a part. The heavy ribs, however, are a gerontic feature, the thin ribs of the spire whorls and the first half of the body-whorl become true, broad varices on the later part of the body-whorl. The same feature occurs in the largest Cantaure specimen where there are two, broad varices prior to the present lip.

Until further evidence is available regarding the relationship between *H. myrmia* and *H. americana,* the Cantaure form is here reassigned to *H. myrmia* as being the more logical assignment, a reassignment that might well apply to the Esmeraldas form, should it not merit identification as a new taxon. Only one difference has been noted; in the Cantaure form there are 13 ribs on the spire whorls, reducing to 11 on the body-whorl, whereas *H. myrmia* has only 9 ribs on the body-whorl, but this may not be diagnostic.

Text figure 3. *Harpa myrmia* Olsson
Height 41.0 mm, diameter 26.8 mm.
Locality: Cantaure Formation, Paraguaná Peninsula, Venezuela.

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TULANE UNIVERSITY OF LOUISIANA

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I. ABSTRACT

The scarcity of fossils in most non-marine Coastal Plain sediments of Tertiary age has surrounded these strata with a multitude of controversies. Not only is it difficult to correlate units believed on the basis of stratigraphic position to be of the same age, but it often poses a similar challenge to differentiate deeply weathered sands and gravels of markedly different ages when they are present in the same general area. As a consequence of this, some units simply have been "lumped" together and terms such as "upper Tertiary coarse clastics" and "undifferentiated Miocene" appear too often on state geologic maps. Further, this same lack of fossils also has led to major disagreements with respect to deposits laid down in more recent times: specifically, the age and number of identifiable terraces that developed by still-stands of the Pleistocene seas and the origin of these terraces (marine *vs.* non-marine?, erosional, depositional, or tectonic?).

Multivariate statistical analysis has proved useful in dealing with the identity of deeply weathered "red sands" in the Alabama Coastal Plain and strongly indicates that some units previously assigned to the Eocene Lisbon Formation are more likely recent terrace deposits. Similarly, detailed examination of sedimentary structures, mineral suites, and gravels has shown that the Miocene sediments in Alabama can be assigned to two mappable units (the Mobile Clay and the Ecor Rouge Sand). Criteria also exist that allow the differentiation of these units from the overlying Citronelle Formation. Recent work on a major vertebrate site, disconformably underlying the Citronelle Formation in Mobile County, Alabama, has also provided new information on the Citronelle age problem but, for several reasons, mis-use of the term "Citronelle" will undoubtedly continue. Similarly, though the controversy involving the number of Pleistocene terraces (and their origin) is far from solved, evidence is present in southern Mobile County, Alabama that clearly shows the deposition of marine features did take place during the Pleistocene and that this deposition took place at elevations in excess of 10 meters above present mean sea level.

II. INTRODUCTION

Though great strides have been made in the past 40 years in unraveling the stratigraphy of the thick sequence of sediments laid down during regression of the Cenozoic seas, controversies still exist regarding the age, origin, and field identification of a number of prominent units. This has resulted, for the most part, because of the extensive series of non-marine coarse clastics that accompanied withdrawal of the sea and emergence of the Gulf Coastal Plain. Deeply-weathered sands and gravels are found throughout the Coastal Plain and have been assigned ages ranging from Cretaceous to late Pleistocene. Identification of these units, however, is frequently predicated solely on factors such as elevation and location within the study area or on some peculiar idiosyncrasy of the unit, such as the composition of the gravel, the presence or absence of certain primary depositional features (massive *vs.* thin bedded), or specific textural characteristics. The unfossiliferous nature of these units, combined with their restricted mineral suites and similarity to other strata in the study area, thus makes it difficult to identify them positively when they occur in "floating sections" or in questionable contact relationships with other similar appearing sediments.

The following, for example, are major problems in the Alabama-Mississippi Coastal Plain that are still the subject of extended debate:

(1) The number of identifiable Pleistocene terraces that are present in the central Gulf Coast and whether these terraces represent erosional or depositional features or are "tectonic" in origin.
(2) The identity and criteria for differentiating units carried on existing maps as "undifferentiated Miocene" and criteria for differentiation upper Miocene "coarse clastics" from similar appearing sediments assigned to the younger Citronelle Formation.
(3) The Citronelle age problem. Specifically, are the units mapped as Citronelle in Mississippi, Alabama and Florida the same age.
(4) The "Lisbon Problem." Coarse clastic sediments assigned to the Eocene Lisbon Formation may actually consist, wholly or in part, of late Pleistocene fluvial deposits.

III. PROBLEMS WITH THE PLEISTOCENE

The Pleistocene history of the Gulf Coast is undoubtedly subject to less agreement among geologists than any other stratigraphic interval. As a case in point, there is yet no unanimity of opinion regarding:

(1) The number and age of alleged terraces that can be identified in the central Gulf Coast.
(2) Whether any "true" remnant Pleistocene depositional features can be identified at elevations greater than 7-10 m above present sea level.
(3) Whether specific deposits assigned to the Pleistocene represent marine or non-marine units.
(4) Whether terrace escarpments of Pleistocene age are littoral or tectonic features.

Terrace Nomenclature

The extensive debate over the number of identifiable terraces that formed as a result of major "still stands" of sea level can probably be traced to the early work of Cooke (1930, 1931). According to Cooke, repeated fluctuations of sea level during the Quaternary Epoch caused the development of seven major terraces, each of which was assigned a name from the area where it was initially described (see Table 1). Fisk (1944) continued this practice in his study of the terraces of the lower Mississippi Valley, but recognized only four such surfaces. Somewhat later, Carlston (1950) mapped escarpments in western Florida and Alabama and, using Cooke's original nomenclature, was able to identify a total of five terraces in Mobile County, Alabama. Doehring (1956), using a somewhat novel approach, argued that because the central Gulf Coastal Plain has undergone a continuous seaward tilting during the Pleistocene, that the terraces should be defined on the basis of their seaward gradient, rather than their elevation. Using this method, the oldest depositional surface would have the steepest slope, followed successively by younger surfaces with lower gradients. Because of the diffi-

Table 1. — Nomenclature for Gulf Coast Pleistocene terrace deposits.

FISK (1944)	COOKE (1966)		CARLSTON (1950)		HARVEY & NICHOLS (1960)
	Morley	(110 m)			
Williana (Aftonian)	Hazelhurst	(84 m)			Citronelle (58-92 m)
Bentley (Yarmouth)	Coharie	(66 m)	Coharie	(58-64 m)	
Montgomery	Sunderland	(52 m)	Sunderland Sunderland	(46-49 m)	Fourth Terrace (40-52 m)
	Okefenokee	(44 m)			
Prairie (Peorian)	Wicomico	(30 m)	Wicomico	(27-34 m)	Third Terrace (24-34 m)
	Penholoway	(21 m)	Penholoway	(18-21 m)	Second Terrace (9-15 m)
	Talbot	(13 m)			
	Pamlico	(8 m)	Pamlico	(6-9 m)	First Terrace (3-6 m)
	Silver Bluff	(2 m)			

culty in establishing true gradients of some of the terraces, Doehring's method has not yet been fully "tested" and thus lacks the widespread support that it may deserve. In more recent years, Cooke (1966) again addressed the Gulf Coast terrace problem and, disagreeing with Fisk, claimed that a total of ten terraces in the Mississippi Embayment could be identified. These ranged in elevation from 1.8 m above sea level (the Silver Bluff terrace) to one identified as far north as Cape Girardeau, Missouri, at an elevation of 107 m (the Morley terrace). Though Carlston recognized only five terraces in Mobile County, Cooke stated that the Silver Bluff and Talbot were well developed on the Coden Quadrangle and, similarly, the 81-m Hazelhurst terrace was also represented in Mobile County. Hence, in Cooke's view, all ten terraces can be identified in Alabama and can be correlated with those occurring at similar elevations on the Atlantic seaboard.

Though the authors do not care to add to the present controversy regarding the number of terraces identifiable in the central Gulf Coast, a "reasonable" number that can be identified on quadrangles in southern Alabama and Mississippi might be the five that were proposed by Harvey and Nichols (1960). Adopting a moderate approach, they identified four actual terraces and a Citronelle "surface" present at the elevations shown on Table 1. The escarpments and "flats" recognized by Harvey and Nichols can be identified on quadrangles of this area and, for convenience, their terminology is used in the road log.

Age of Terraces

Leighton and Williams (1949), historically, first called attention to the age problem of

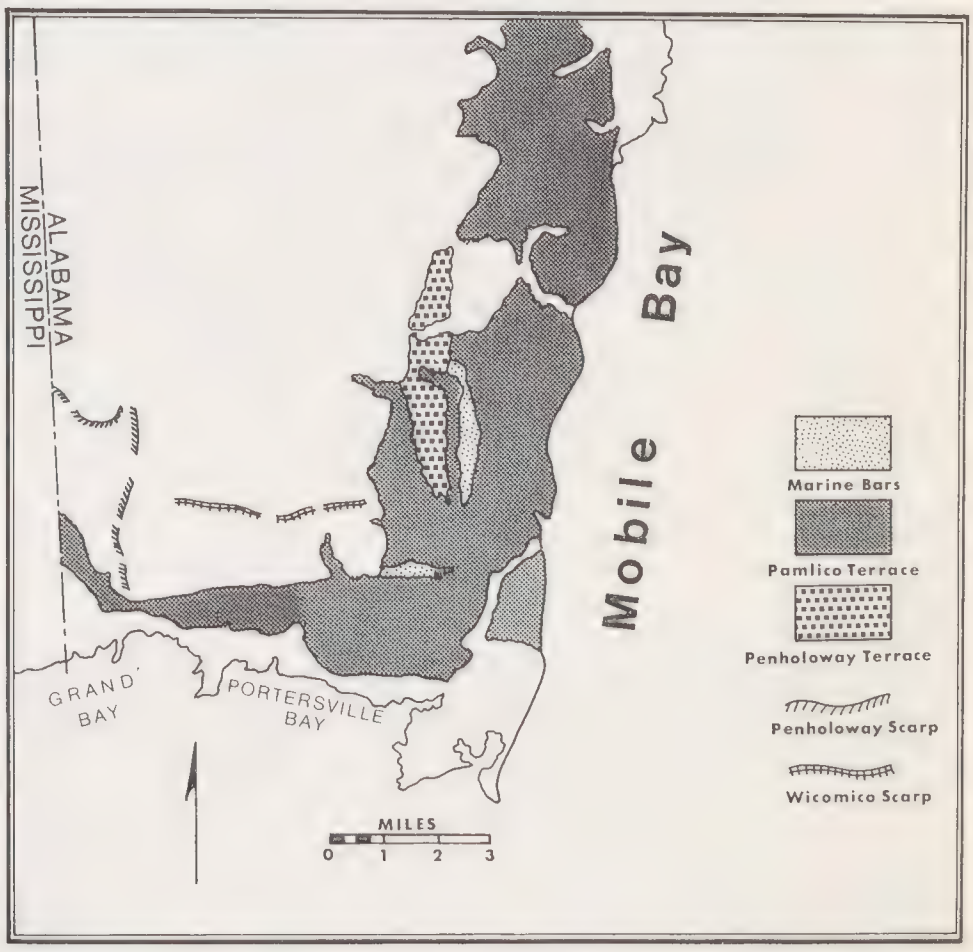

Figure 1. Pleistocene depositional surface features and escarpments (modified after Carlston, 1950).

the "Pleistocene" surfaces in the central Gulf Coast and suggested that at least some of the older terraces might be pre-Pleistocene. Similarly, Alt and Brooks (1965) agreed that the higher terraces were not Pleistocene features and stated that all terraces at greater than 25 meters in elevation were late Miocene to Pliocene in age and only those at elevations of less than 8 m could be assigned a Pleistocene age. Tanner (1965, 1968), and later Osmond *et al.* (1970), concurred that no Pleistocene shorelines had existed at elevations of greater than 10 meters. More recently, Otvos (1972, 1981) has stated that the maximum Pleistocene sea level was only 7 m in elevation above present sea level and that no relict shorelines or barriers of any age occur at elevations higher than this in Mississippi, Alabama, or Florida. Relict barriers of Miocene to Pliocene age, however, have been described by Gremillion *et al.* (1964) and Tanner (1966) at elevations of up to 80 m and, more recently, Winker and Howard (1977) identified extensive beach ridge plains and relict shoreline features, traceable throughout the western Florida panhandle on an upland surface reaching a maximum elevation of 100 m. The authors, likewise, would call attention to two prominent linear features in southern Mobile County that, we believe, are marine Pleistocene features (see Figure 1). The first consists of a north-south trending, curvilinear marine bar that is approximately 8.7 km long and 1.6 km wide. Near the town of Theodore, the elevation of the bar is 18 m whereas at its southern end the elevation is about 13 m above sea level. The sediments comprising this unit consist of clean, cross-bedded, well-sorted sands (see Figure 2) and differ markedly from those of nearby Citronelle and Miocene Formations. There is little doubt that they are Pleistocene in age (Penholoway, according to Carlston, 1950) and were deposited in the form of a southward-developing, prograding, marine bar. Approximately 4.75 km north of the present shoreline (see Figure 1), a second spit-like feature extends eastward for approximately 6.2 km, and is "attached" on the west to an east-west trending wave-cut

Figure 2. Cross-bedded "bar" sands exposed in pit in southern Mobile County.

cliff that parallels Mississippi Sound. The spit varies in width from nearly 355 m on the west, where it merges with sands of the Citronelle Formation, to approximately 1.6 km at its eastern extreme where it is dissected by parallel, easterly flowing streams that empty into Fowl River. The crest of the spit is at an elevation of 11 m and the sediments that form the spit are typical marine, estuarine, and stream deposits that have been assigned an upper Pleistocene (Pamlico) age.

The existence of both of these features, thus, provides evidence that remnant Pleistocene littoral structures do exist at greater than 7-10 m above sea level and that Pleistocene sea levels must, therefore, have exceeded 10 m in order to account for their formation.

Origin of the Pleistocene Escarpments

Extending westward from the Pleistocene spit described in the previous paragraph is an easily followed escarpment that can be traced from southern Mobile County, Alabama, to beyond Biloxi, Mississippi. This escarpment may be viewed at two sites of the field trip, one north of Biloxi, where it is called Big Ridge Scarp, and again in Alabama, just north of the town of Bayou La Batre. While usually interpreted as a shoreline feature (the "Pamlico" shoreline), Otvos (1981) has suggested a tectonic origin for the scarp and attributes its origin to faulting. He offers as evidence (in the area of Big Ridge Scarp) the following features:

(1) The lateral continuity of the feature with lineaments on adjacent, younger land surfaces.
(2) Sag pond-like marshy lows along the toe of the scarp.
(3) Its essential straightness.
(4) The basic flatness of its upper surface, both in constancy of elevation and lack of cross-sectional symmetry considered characteristic of beach ridges.
(5) Its parallelism with other lineations occurring to the north.

Otvos' tectonic origin is certainly deserving of consideration, especially in light of recently acquired geophysical evidence that does indicate the presence of a major east-west trending fault at depth in the general vicinity of the escarpment in southern Mobile County, Alabama. Whether or not this fault does produce surface expression, however, is another matter, especially in view of the fact that the escarpment has been traced into peninsular Florida, and northward, along the Atlantic Coast and, as such, closely resembles a shoreline feature.

Figure 3. Outcrop of Miocene sediments in Gulf Coast showing source areas.

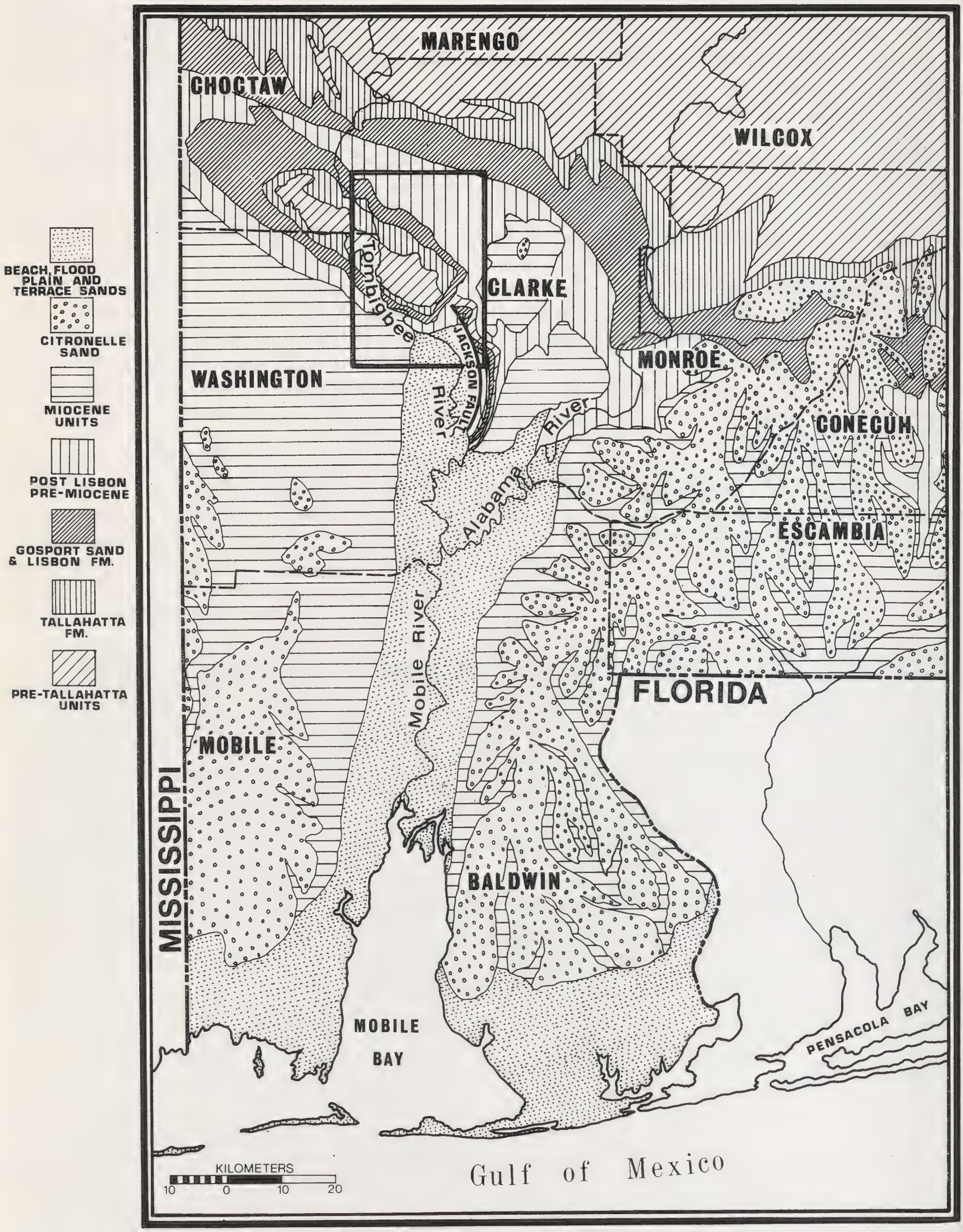

Figure 4. Simplified geologic map of southwestern Alabama. The misclassified clastics mentioned in the discussion of the Lisbon Problem (see text) occur in the area indicated by the rectangle.

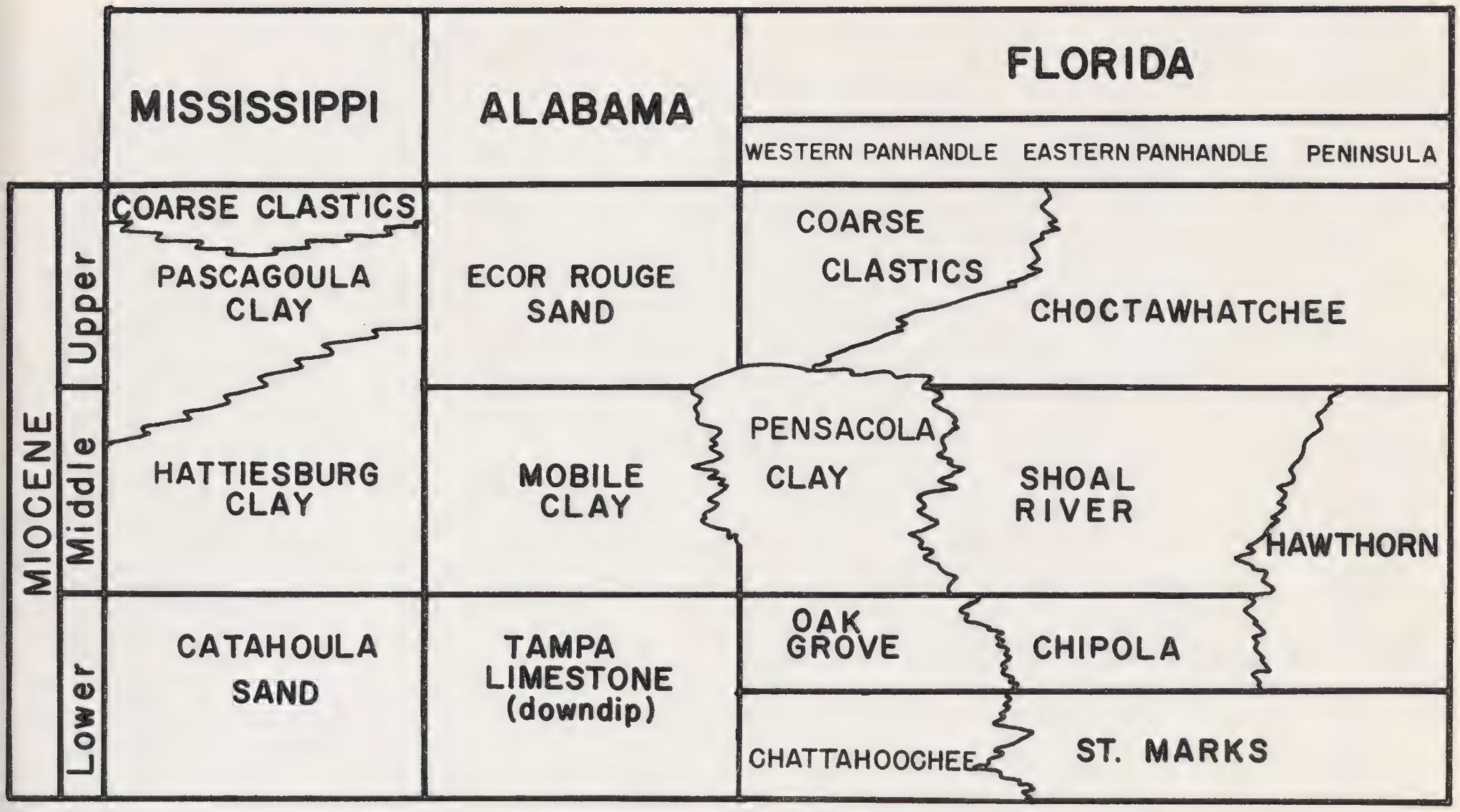

Figure 5. Generalized Miocene correlation chart for Mississippi, Alabama and Florida.

IV. THE "UNDIFFERENTIATED" MIOCENE OF ALABAMA

Miocene sediments crop out almost continuously from Texas eastward to the Florida peninsula (Fig. 3) and reflect deposition that took place in the Gulf Coast Geosyncline at a rate second only to the present. These strata consist, largely, of fluvial and transitional marine deposits, in Texas, Louisiana and Mississippi, and marine and transitional marine deposits in Alabama and Florida. Lithologies, locally, are quite varied and range from thick clastic sequences containing large quantities of volcanic detritus in Texas, to a relatively thin section of limestones, phosphatic sands and clays, and attapulgite clays that were deposited on the emerging Florida platform. The Alabama section is the least investigated of Miocene units in the Gulf Coast, but is important because it represents sediments that were apparently deposited on the eastern margin of the rapidly subsiding Gulf Coast depositional basin (see Isphording, 1977).

Sediments assigned a Miocene age form an outcrop band some 80 km wide (Fig. 4) and dip southward at a rate of 2 to 9 m/km (Reed, 1971). Most Miocene outcrops consist of either white, red, orange, or light brown, very fine- to coarse-grained sands with locally abundant ironstone lenses or consist of massive to laminated, green, grey, lavender or "brassy-colored" clay beds. Lenses of gravel are common in the sand units and range up to 3 m in thickness. Detailed examination of outcrops and well logs has allowed this sequence to be subdivided into a lower, dominantly clay unit, of marine and transitional marine origin, and an upper sequence of sands and gravelly sands of fluvial origin. The name Mobile Clay was suggested earlier by Isphording (1977) for the lower sequence and several locations may be seen on the field trip where clays of this unit are exposed (see Fig. 6). Examination of numerous well logs from Mobile and Baldwin Counties indicates that, downdip, this formation is represented by nearly 445 m of marine, fossiliferous, greenish clays and clayey sands that are contemporaneous with the middle Miocene Pensacola Clay, found eastward in the west Florida panhandle (Fig. 5). Overlying this middle Miocene clay sequence, con-

formably, is a 150- to 230-m section of coarse clastics, consisting of sands, gravelly sands, sandy gravel, with occasional thin lenses of kaolinitic clay, that are probably correlative with the late Miocene coarse clastics that overlie the Pensacola Clay in the western Florida panhandle. Excellent exposures of these sediments can be seen in Mobile, Washington, and Baldwin Counties where they are often capped, on the higher hills, by a thin veneer of sands and gravels of the Citronelle Formation. Perhaps the finest exposure of these upper Miocene sediments is found at Ecor Rouge (near Sea Cliff) on the eastern shore of Mobile Bay (see Fig. 7). This location, which is reported to be the highest point of land in the United States on the combined Atlantic and Gulf Coasts, reveals nearly 12 m of thin laminated clays, ironstones, cross-bedded sands and gravelly sands that are overlain by some 3 m of reddish-brown, fine to medium sands of the Citronelle Formation. As such, this site serves as the "type section" for the unit, which was named the Ecor Rouge Sand by Isphording (1977). Another excellent exposure of these upper sands is found on Wolf Ridge Road, near the northern Mobile city limits where approximately 10.5 m of sediments of the Ecor Rouge Sand are exposed. This exposure (STOP 4) also contains a prominent cut-and-fill structure of deeply weathered, reddish-brown sands of the Citronelle Formation and demonstrates well the fact that Citronelle sediments occur, chiefly, as a relatively thin, "drape" over the Miocene strata in the south Alabama area. Though some older reports claim difficulty in differentiating the upper Miocene sands from Citronelle deposits, the disconformably relationship is readily apparent in most exposures (see Fig. 8) and criteria are present that generally allow their immediate identi-

Figure 6. Bedded Miocene clays ("Mobile Clay") exposed in road cut on Highway 45, Mobile County, Alabama.

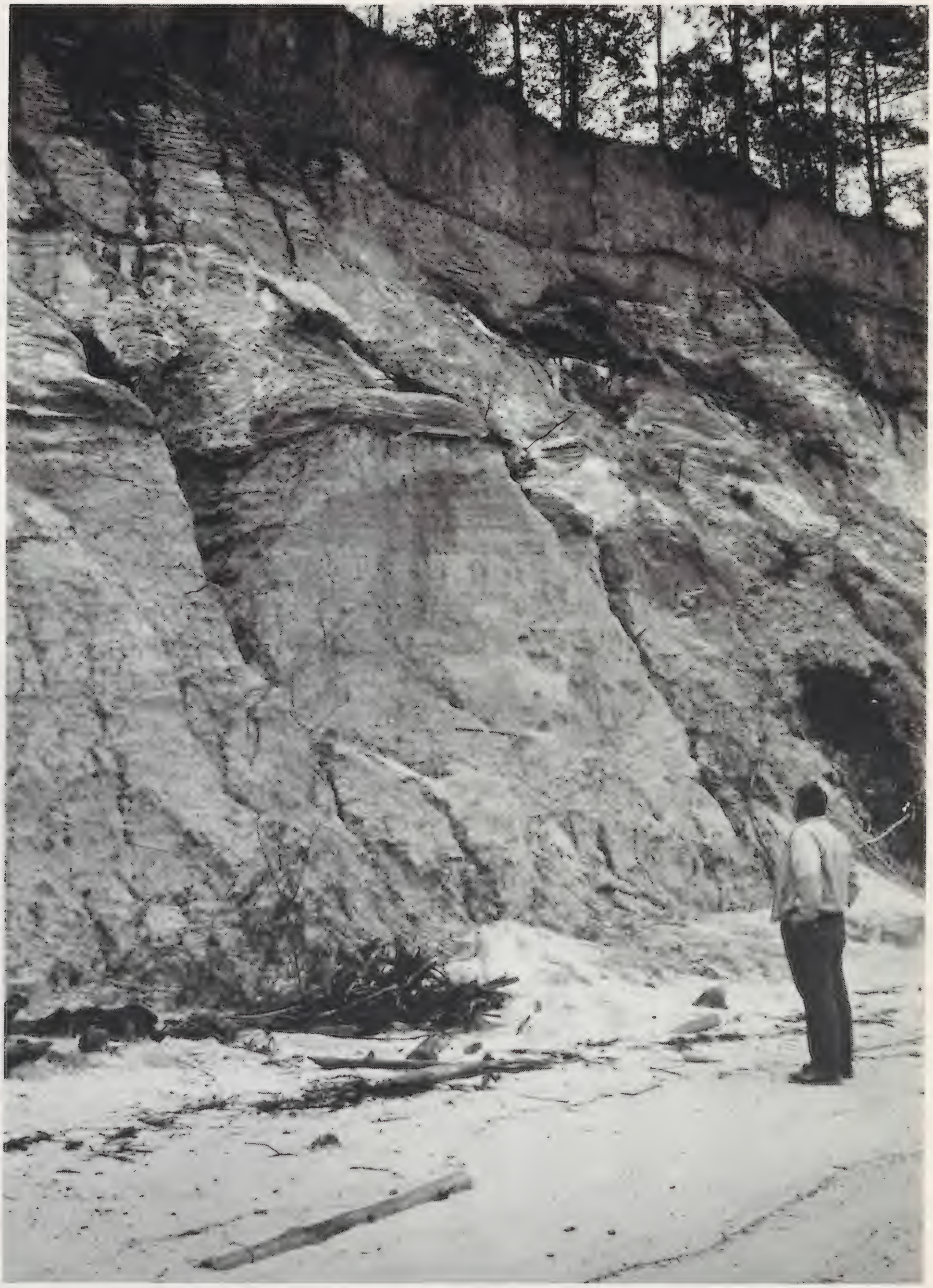

Figure 7. Upper Miocene sands ("Ecor Rouge Sand") exposed at type locality near Fairhope, Alabama.

	Citronelle Formation	Ecor Rouge Sand
1.	Sands consist of massive, deeply weathered, iron-stained quartz.	Sands are white, brown or reddish brown and usually display bedding or crossbedding. Liesegang banding is locally common.
2.	Gravels present are also highly iron-stained and consist of a mixture of quartzite and chert pebbles.	Gravels are typically white or tan and are largely quartzitic in composition.
3.	Many outcrops characterized by presence of highly polished, ironstone granules and small pebbles of polished ironstone.	Ironstone pebbles and granules, when present, are angular to sub-angular and lack the high polish found on those in the Citronelle formation.
4.	Heavy mineral suite:	Heavy mineral suite:
	Ilmenite 30-40% average	Ilmenite 15-20% average
	Tourmaline 5-8% average	Tourmaline 10-20% average
	Rutile 5-7% average	Rutile 2-3% average
	Zircon 5-15% average	Zircon 1-4% average

Table 2. — Criteria for differentiation of upper Miocene Ecor Rouge Sand from Citronelle Formation.

fication (see Isphording, 1976, 1981). These properties are summarized in Table 2 and may be observed at several stops on the field trip.

V. THE CITRONELLE AGE PROBLEM

Sediments assigned to the Citronelle Formation have been described in such diverse locations as Texas, Alabama, Louisiana and as far north as South Carolina. Stratigraphically, these units are found resting, unconformably, on formations that range in age from late Oligocene to early Pliocene. They are, in turn, overlain by Pleistocene-age fluvial, estuarine, terrace and high terrace deposits. This thickness of the formation cannot be determined with certainty, in many locations, because reworking has resulted in the incorporation of the materials into overlying Pleistocene deposits or into younger colluvial deposits that are too similar in physical and mineralogical properties to allow differentiation. Best estimates place the maximum thickness at approximately 85 m near the Alabama-Mississippi border, with most other locations having sections ranging from a few tens of feet to less than 45 m.

The sediments of the Citronelle Formation were originally described and given formational status by Matson (1916). The original type section of the formation, at Citronelle, Alabama, may be visited on the field trip (STOP 5).

In the same year that the formation was named and the type section described, Berry (1916) discovered plant fossils in a clay bed at an exposure on the Gulf, Mobile and Ohio Railway right-of-way, six miles south of Citronelle and, on the basis of the flora, confirmed the Pliocene age originally suggested by Matson. Since that time, the clay bed has been the subject of extended discussion, with Roy (1939) claiming that the bed is separated from the overlying Citronelle by a low-angle fault, whereas Carlston (1950) believes that a disconformity is present. Stringfield and LaMoreaux (1957) argued that an unconformity, even if present, was minor in extent and that this would not preclude the plants from belonging to the Citronelle Formation. They also noted that a similar leaf-bearing clay horizon was present at Red Bluff on Perdido Bay west of Pensacola, Florida, and was underlain by sediments of typical Citronelle lithology. Isphording has examined the plant locality and was unable to find any definite evidence of either a fault or unconformity. The sands overlying the clay horizon did appear to have been subjected to some penecontemporaneous deformation, however, but this died out laterally after a distance of a few tens of meters.

Regardless of the stratigraphic position and relationship of the clay bed, additional

controversy arose when Doehring (1958) questioned the age of the flora described by Berry and concluded that there was no valid reason to assign a Pliocene age and that an early Pleistocene age was more logical. Marsh (1964) reported that this conclusion was supported by pollen studies that were carried out by Estella Leopold, who stated that the flora present (p. 83) ". . . provides clear fossil evidence of a Quaternary age for the middle and upper parts of the Citronelle Formation in westernmost Florida." Alt and Brooks (1965), however, after studying the soil associations and distribution of major terrace deposits in the east Gulf Coast, concluded that the Citronelle Formation, at least in peninsular Florida, probably deserved a late Miocene age and that they could (p. 408) ". . . find no evidence to favor the Pleistocene age proposed by numerous authors." Their conclusions supported earlier studies carried out by Ketner and McGreevy (1959), who also believed that the Citronelle sediments of the Lake Wales Ridge area of Florida should be assigned a late Miocene age. The Citronelle Formation, hence, may be variously designated as late Miocene, as Pliocene, as Plio-Pleistocene, or as Pleistocene, depending upon where in the Gulf Coast its sediments are described (and to whom in the Gulf Coast you are talking!). Obviously, the age problem of the Citronelle Formation reduces to a simple lack of vertebrate or invertebrate fossils on which a reliable date may be placed.

The search for fossils that would finally allow the formation to be dated was accidently rewarded about ten years ago when a student in an introductory geology course at the University of South Alabama casually mentioned that a clay bed containing some "old bones" was exposed in a creek on his uncle's land, in northern Mobile County. A visit to the site revealed the presence of some 2+ m of bedded, dark gray, carbonaceous, silty clay and clayey sand overlain, disconformably, by typical coarse clastic

Figure 8. Citronelle sands containing abundant highly-polished ironstone pebbles lying disconformably on Miocene clays (Mobile County, Alabama).

Figure 9. Vertebrate fossil locality on Chickasabogue Creek, northern Mobile County (NW ¼ Sec. 27, T2S, R2W).

sediments of the Citronelle Sand (Fig. 9). The unit contained an abundance of wood fragments and, most important, an interval of about 0.6 m that contained abundant vertebrate remains. A number of the fossils were gathered by Dr. George Lamb and shipped to the U. S. National Museum and, shortly thereafter, Dr. Frank Whitmore (U. S. Geological Survey/U. S. National Museum) visited the site. Additional fauna were removed and were identified by Dr. Whitmore and his colleagues. A list of the fauna described at that time may be found in an article by Isphording and Lamb (1971). Unfortunately, before the site could be excavated to Dr. Whitmore's satisfaction, the landowner became suspicious that something "valuable" was being removed and refused permission for further excavation unless suitable "compensation" was forthcoming. Thus, for nearly ten years, no further work was carried out. Late in 1981, however, the former landowner's son took possession and again allowed entrance to the sitė. Dr. Whitmore returned and carried out an extensive excavation, which may be viewed on the field trip at STOP 4. The fauna collected during this recent field visit are presently being analyzed by Dr. Whitmore and his colleagues at the U. S. National Museum and he has kindly consented to supply the following description of the site for inclusion here.

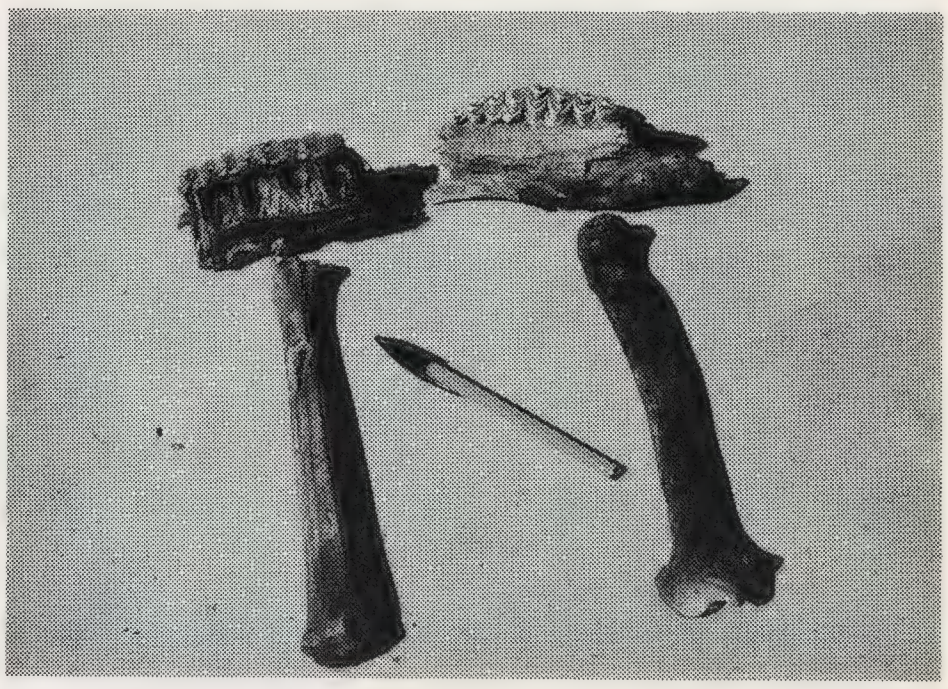

Figure 11. Protoceratid and horse fossils collected at vertebrate fossil site, northern Mobile County, Alabama.

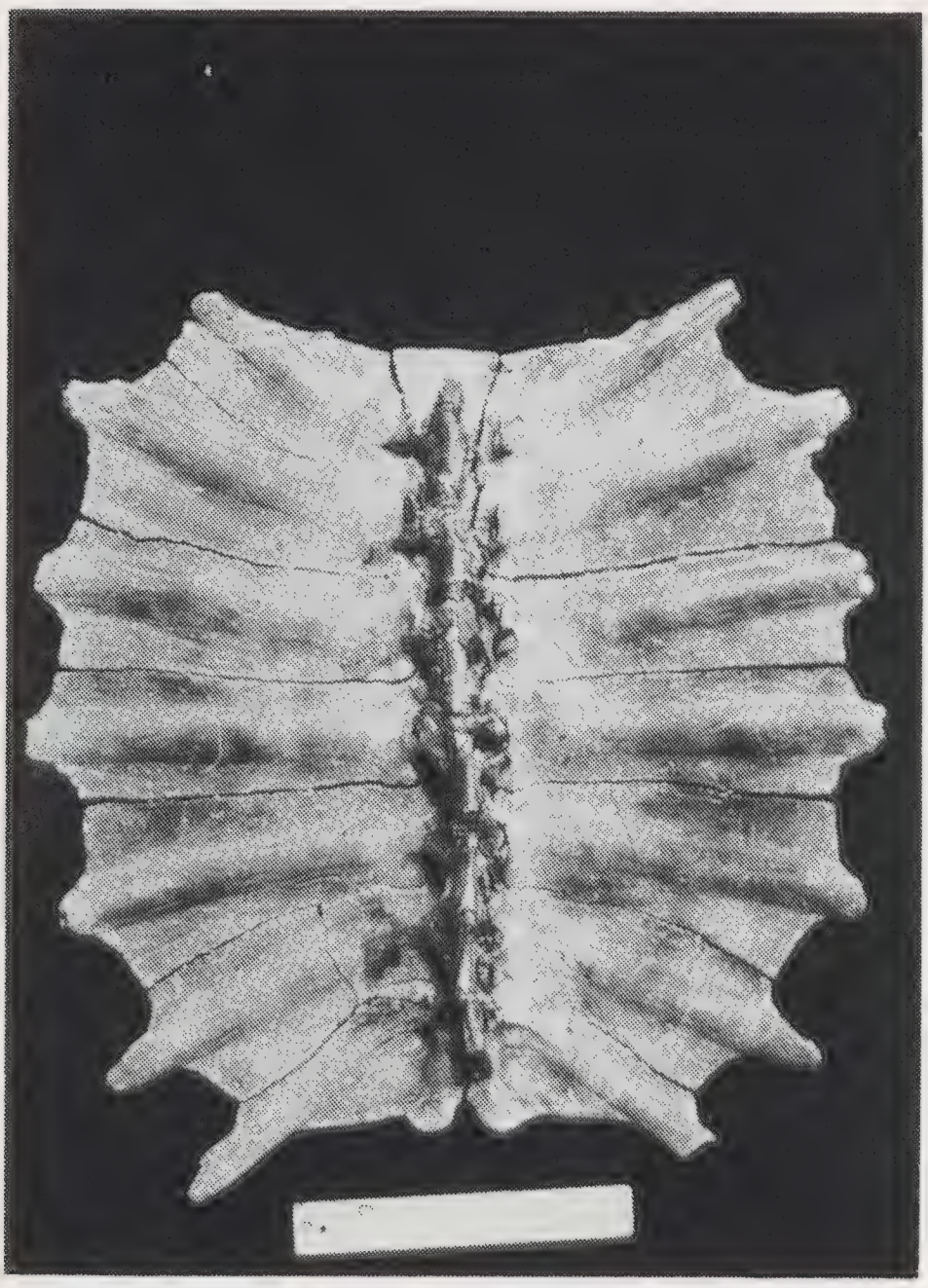

Figure 10. *Trionyx* species of soft-shelled turtle (either *spinifer* or *farox* species) from fossiliferous unit at vertebrate fossil site, northern Mobile County, Alabama.

Hemphillian Vertebrate Fauna From Mobile County, Alabama

Frank C. Whitmore, Jr.
U. S. Geological Survey

A vertebrate fauna of Hemphillian age (Late Miocene to early Pliocene, or about 10 to 3.5 mya according to Berggren and Van Couvering, 1974, Fig. 1), occurs on the right bank of Chickasabogue Creek, in northern Mobile County, 1.5 km northeast of the town of Mauvilla.

The bones are found in a gray clay with thin intercalated sand beds, mapped by the Alabama Geological Survey as Miocene Undifferentiated and underlying the Citronelle Formation. The bones, occupying a stratigraphic thickness of about 60 cm and lying about 2 m below the top of the clay were associated with large logs, ranging from 0.5 m to almost 1 m in diameter and oriented subparallel, between N30°E and N50°E. The largest concentration of bones, all of which were disarticulated, lay close against the west sides of the logs in association with large amounts of woody trash.

Soft-shelled turtles *(Trionyx)* were the most numerous components of the fauna (see Fig. 10). Land tortoises were also present, and gar scales were very numerous. The lower jaw of a long-beaked porpoise *(Pomatodelphis inaequalis)* was collected by the author and George Lamb at the

site in 1967, but further digging has produced no more porpoise bones.

Land mammals of the fauna included the rhinoceros *Teloceras*, the horses *Hipparion* and *Nannippus* (see Fig. 11), the protoceratid (horned ruminant) *Synthetoceras* (Fig. 11), a large camel, peccary, and a large beaver, near *Castoroides*. The bones are fresh and unabraided, so they do not appear to have been transported far; some of them show signs of having rotted, probably subaqueously. A jawbone of an infant protoceratid bears tooth marks on both sides, from the canine teeth of a carnivore. No carnivore bones have yet been found in the collection (preparation of which has just begun).

The clay in which the bones are found shows cyclic sedimentation, with repeated alternation of clay beds (about 10 cm thick) and gray sand stringers (2 to 3 cm thick). Most of the bones are in sand stringers, embedded in the top of a clay bed.

From the freshness of the bones, it is probable that they represent a fauna inhabiting a single small drainage basin. They were probably deposited during floods in a backwater where there was little current, except during flood stage. The puzzling presence of a long-beaked porpoise may be explained by the hypothesis that *Pomatodelphis* was a fresh water porpoise. *Inia*, the long-beaked Amazon porpoise, has been reported as observed swimming through the woods during Amazon floods.

One additional major conclusion that may be drawn from Dr. Whitmore's work is the fact that the obvious unconformable contact with the overlying Citronelle clastics places a minimum age on the formation. Deposition of the Ctironelle could not have begun before the middle Pliocene and appears to have continued into the pre-Nebraskan Pleistocene (based on pollen data from upper Citronelle sediments in the western panhandle of Florida).

The Citronelle age problem itself, however, will unfortunately continue to persist in the Gulf Coast because of the historical misuse of the term "Citronelle Formation." This is particularly true in the case of the sands that form Lake Wales Ridge and Trail Ridge, in peninsular Florida. Because it has been fairly well established that these sediments are late Miocene in age, they cannot thus belong to the "same" Citronelle For-

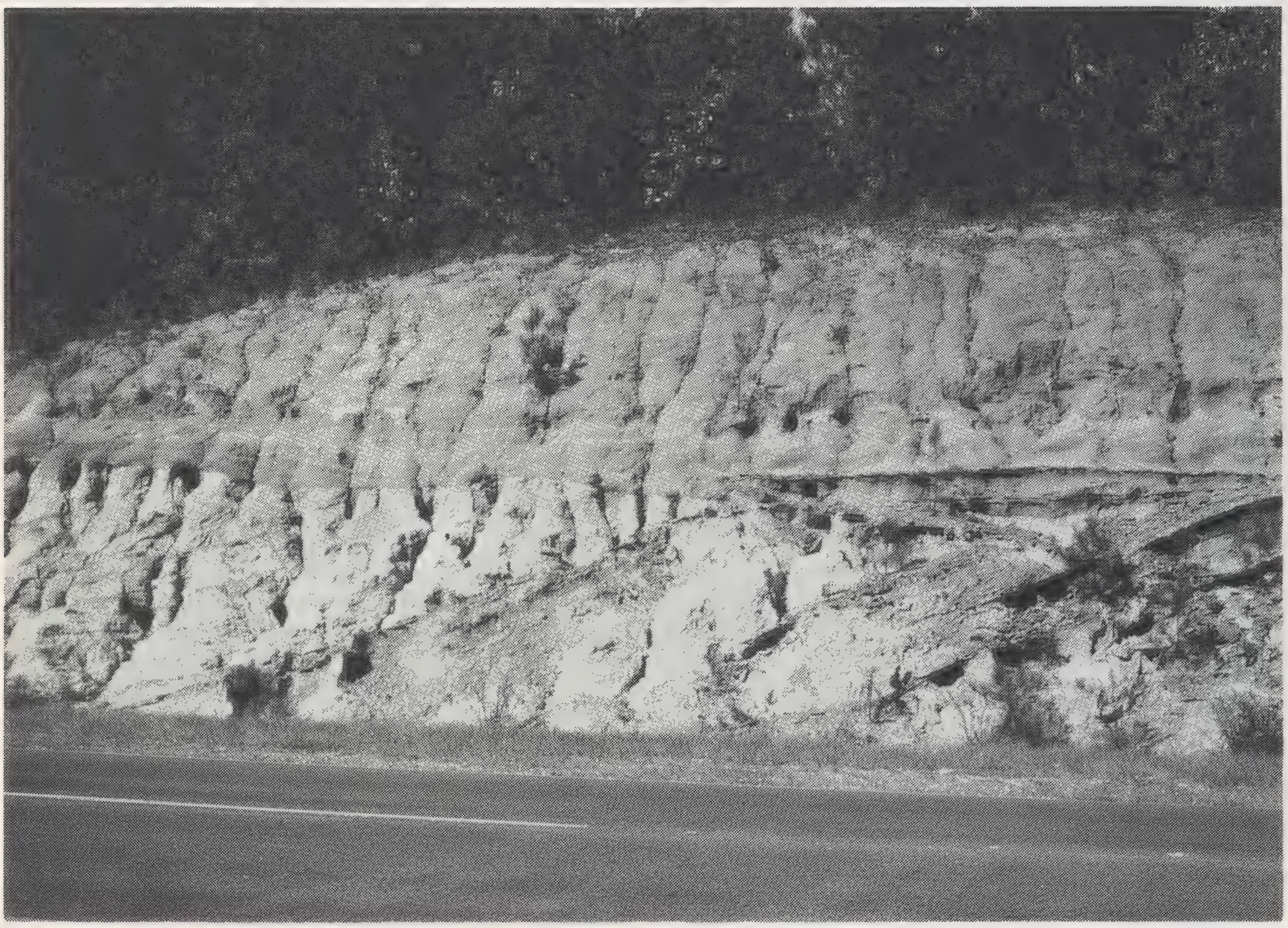

Figure 12. Terrace sands lying on dipping Miocene strata, near Jackson, Alabama.

mation that is described at the type locality in Alabama and should, therefore, be redefined. Further, even in south Alabama, problems with the Citronelle will continue because of the similarity in appearance of these sands to those of younger (or contemporaneous!) terrace deposits. The Citronelle Formation is largely the aggradation product of coalescing, braided streams and, as such, is identical in depositional environment to most other terrace sediments. It has also been subjected to the same weathering regimen as the terrace sands and, thus, is expectedly similar in general appearance. For this reason, sands overlying Miocene sediments on the south side of the Tombigbee River, at St. Stephens, Alabama, were designated on State maps as "Citronelle," whereas those on the north side were termed "terrace deposits" (see Fig. 12). The problem is even more acute in southeastern Mississippi where little in the way of agreement is found on what to map as Citronelle and what to call terrace deposits. The problem in establishing what truly "belongs" to the Citronelle may, therefore, be insurmountable because it might actually require developing a means of defining the depositional limits of individual "terrace" sands that were deposited during the late Pliocene and Pleistocene.

VI. ALABAMA LISBON PROBLEM

In Washington, Clark, and Choctaw Counties in southwestern Alabama, many hills are capped by a conspicuous, massive red sand (see Fig. 13). The appearance of this sand is very similar to sediments of the Citronelle Formation, the Miocene Ecor Rouge Sand, and high terrace deposits of the Tombigbee River. For the most part, these sands have been mapped as belonging to the Middle Eocene (Claibornian) Lisbon Formation. In the light of multivariate statistical analysis of heavy mineral populations and corrobrating field evidence, Isphording and Flowers (1980) sug-

Figure 13. Red sands (Lisbon?) lying on Tallahatta clays and claystones, Clarke County, Alabama.

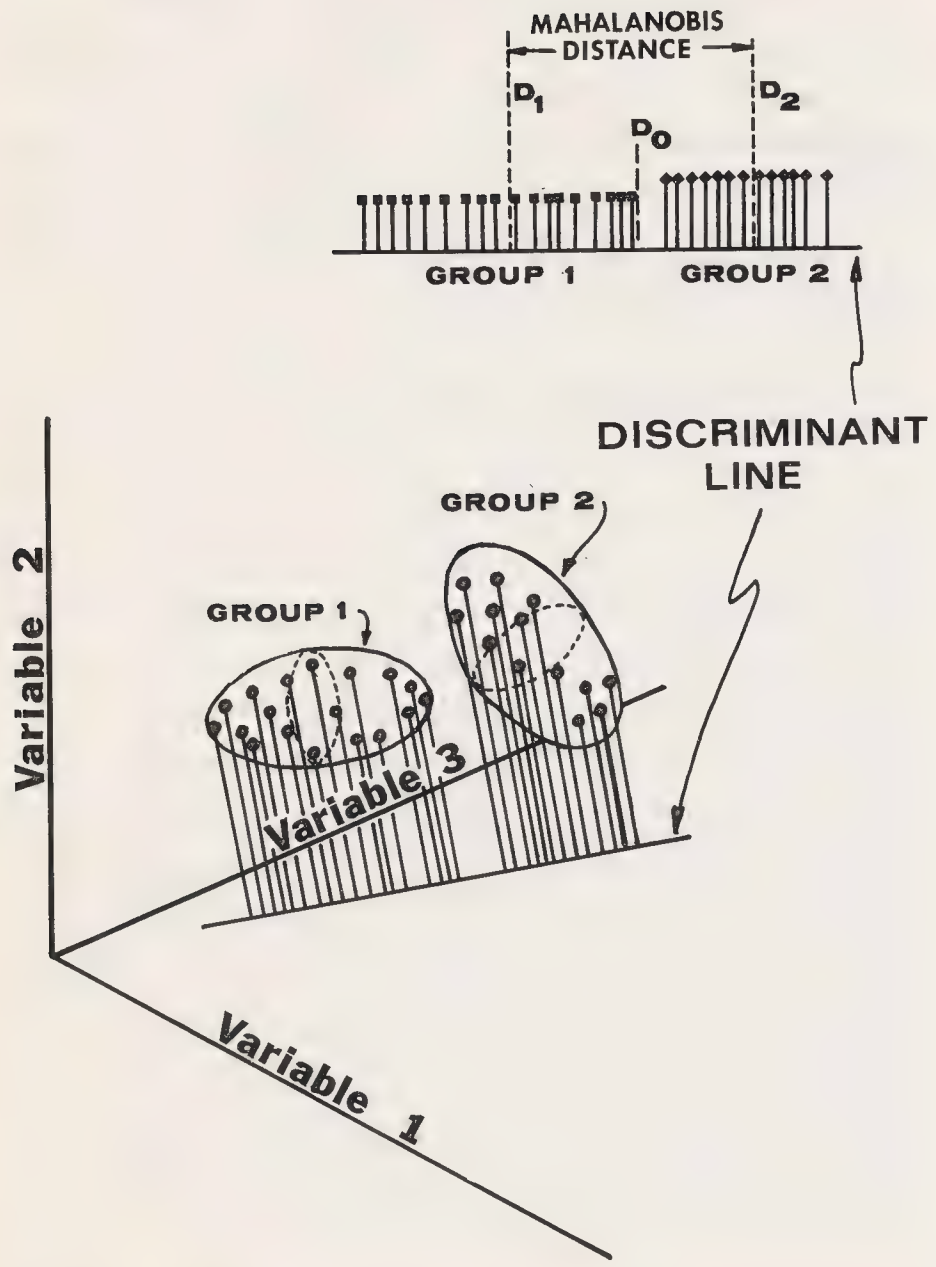

Figure 14. Schematic representation of the relationship between the discriminant function and distributions for groups 1 and 2.

gested that the "blanket" assignment of red sands to the Lisbon Formation may not be warranted. A summary of the evidence for this conclusion is presented below.

Statistical Analysis

It is reasonable to assume that sediments deposited at different times or in different areas will display variability in the relative abundance of different heavy mineral species. Further, even if no variability exists in the species found in two different formations, differences would be expected in the individual mineral ratios. Factors such as basin configuration, particle size, hydraulic selectivity, and the availability of a given mineral constituent would, thus, give rise to modal variation in the heavy mineral suites of any two formations. The problem encountered by geologists considering impoverished heavy mineral populations, however, is how to "distill" the differences among several groups, especially if such differences are subtle. Fortunately, the multivariate statistical technique of discriminant analysis provides an approach to this problem.

Discriminant analysis is a linear transformation of original variables, which maximizes the difference between groups while minimizing the scatter within each group. It can be seen in Figure 14 that the transformation, in addition, reduces the dimensionality of the problem and provides a simple discriminant function, which can be used to assign observations to one group or the other. The discriminant for the ith observation can be expressed as:

$$D_i = \sum_j d_j X_{ij}$$

where d_j denotes the discriminant coefficient for the jth variable, and X_{ij} refers to the value of the jth variable for the ith observation. The mean discriminant score for each group (designated by D_1 and D_2 in Figure 14) is calculated by substituting the mean value of each variable into the above equation. The difference between the mean discriminant score for the two groups is called the Mahalanobis Distance (D^2), which is a measure of the separation or distinctness of the two groups.

Isphording and Flowers (1980) used discriminant function analysis to test the hypothesis that modal variation in the heavy mineral suite alone was sufficient to determine whether or not sand samples were taken from the same population (group). Heavy mineral analyses for samples taken from the Cohansey Sand (New Jersey) and the Citronelle Formation (Alabama) were considered in the analysis. Both of these sands are characterized by an

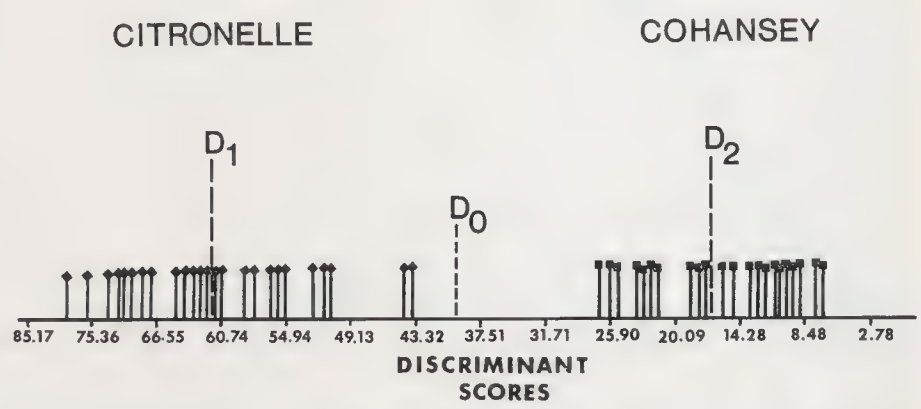

Figure 15. Plot of discriminant scores for Citronelle and Cohansey formation samples.

impoverished heavy mineral suite, consisting of the stable to ultrastable heavy minerals: kyanite, rutile, staurolite, tourmaline, zircon, ilmenite, and leucoxene. As can be seen in Figure 15, the discriminant function was extremely efficient in segregating the two groups, demonstrating that the procedure could be used as a classification tool.

Application to the Lisbon Problem

The Lisbon Formation in southwest Alabama consists of a sequence of greenish gray glauconitic clays, sandy clays and sands that are frequently weathered to a deep reddish-brown color. As such, exposures of these dominantly sandy sediments frequently resemble a number of other younger clastic units that occur in southwestern Alabama. Comparison of heavy mineral analyses for these clastic units and the red sands indicated that all had essentially the same heavy mineral suite. This fact, combined with the similarity in appearance and the frequent occurrence of erosional contacts, makes differentiation of these units difficult, particularly in the case of "floating" sections. Discriminant function analysis was used by Isphording and Flowers (1980) to see if a new variable, formed as a linear combination of the heavy mineral percentages, could aid in the classification of red sand exposures. The results of pair-wise analysis, which compared the mineralogy of each of the known groups (terrace, Miocene, Citronelle, and Lisbon sediments) with the red sands, are shown in Figure 16. Comparison of the Mahalanobis Distance for each analysis suggested that a number of the red sands mapped as belonging to the Lisbon are closer in character to high terrace deposits of the Tombigbee River. The results of multiple discriminant analysis, a procedure where all groups are considered simultaneously, were more definitive. The majority of the red sands were classified as high terrace deposits, with a smaller number classified as belonging to the Lisbon Formation. In many cases where the coarse red sands had been classified as Lisbon sediments, field evidence also suggested that an unconformable relationship between the massive red sand and the finer, laminated Lisbon clays and silts was present (see Figs. 17 and 18). The field evidence, further, indicated that a Lisbon "character" was frequently imparted to the terrace sands in some areas due to extensive reworking of older Lisbon sediments.

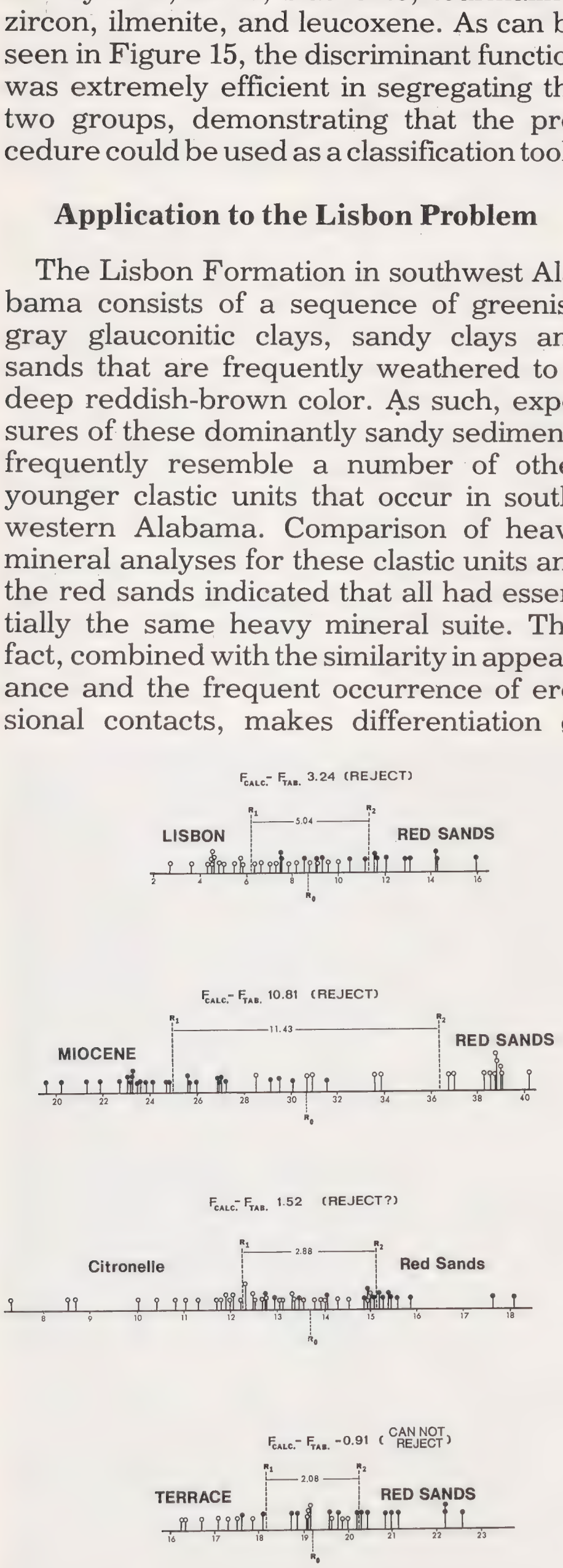

Figure 16. Pair-wise discriminant plots for "red sands" versus Lisbon, Miocene, Citronelle and Terrace sands.

Analysis of these "Lisbon" sediments thus demonstrated that multivariate statistical techniques could be used to examine the contact relationships of sediment units, as well as to provide a means of classifying "floating" sections. Specifically, the following conclusions were drawn from the analysis:

1. Discriminant function analysis is effective in differentiating sedimentary units of identical mineralogy and similar depositional environments, solely on the basis of modal variation.
2. Large Mahalanobis Distances indicate different provenance for sedimentation units of the presence of a diastem or unconformity.
3. Failure of the analysis to discriminate two units suggests that the units have the same provenance and/or that both were deposited at nearly the same time.

4. Failure of the analysis may also indicate the reworking of older material into a younger sedimentation unit.

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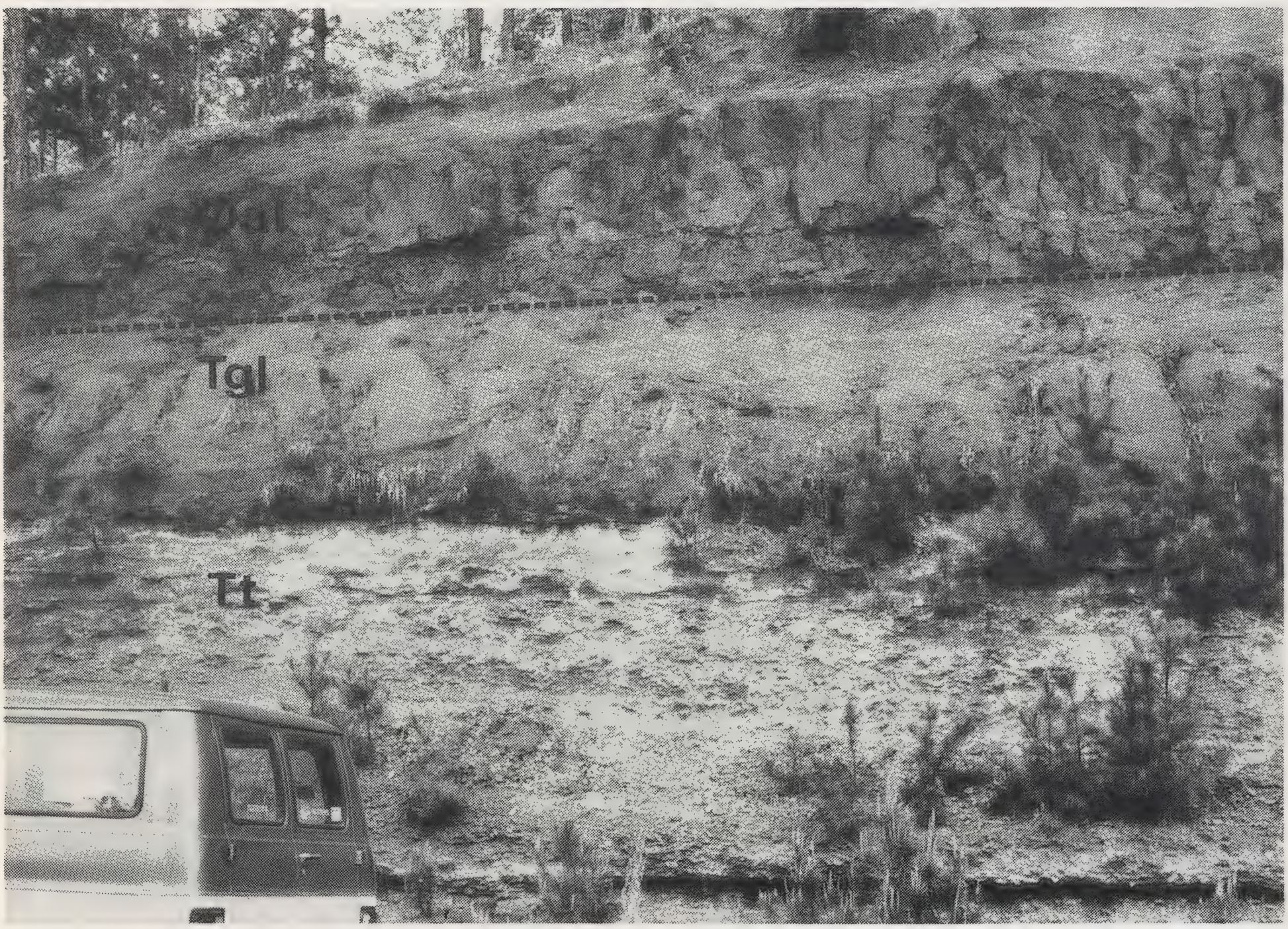

Figure 17. Massive red terrace sands in contact with upper sands and clays of Lisbon Formation (Tgl). Lisbon-Tallahatta (Tt) contact also visible.

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Figure 18. Red sands forming large cut-and-fill structure which extends through Lisbon sediments into the lower Claibornian Tallahatta Formation.

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VIII. APPENDIX: Field Trip — New Orleans to Jackson, Alabama

ROAD LOG FIRST DAY OF FIELD TRIP

Mileage

0.0 Marriott Hotel, New Orleans, La. Proceed northwest toward Lake Pontchartrain on Canal St.

0.7 Turn right on North Claiborne Avenue and proceed northeast toward the Interstate 10 on ramp.

1.4 Junction I-10. Proceed on Interstate 10 East. This portion of New Orleans is built upon sediments of the subsided St. Bernard Delta, which was active from about 4500 to 1000 years B.P.

4.5 High rise bridge over the Inner Harbor Navigation Canal.

5.3 Crest of the high rise. From this point a rare panoramic view of the New Orleans East area can be seen. Straight ahead (to the east) the subsided surface of the St. Bernard Delta Plain can be seen. Also visible from the bridge is a St. Bernard distributary levee, marked by the stand of hard wood trees adjacent to the railroad tracks on the right side of the bridge. This levee is associated with the Bayou Sauvage distributary channel (Kolb *et al.*, 1975). On the left side of the bridge can be seen Lake Pontchartrain, a large land locked coastal bay. The large canal on the southeastern side of the high rise is the Mississippi River-Gulf Outlet. Relatively undisturbed marshes can only be seen just before crossing the Lake Pontchartrain bridge. Most of the area between the high rise and the Lake Pontchartrain bridge is an old cypress swamp and brackish to fresh water marsh, which is being prepared for development by draining and filling.

10.8 Top of the overpass at the Bullard Ave. exit. To the northeast a borrow pit can be seen. In this pit was exposed the largest section of late Quaternary deposits in the New Orleans area. Unfortunately, this pit has been filled with water, so as to create lake front property for a subdivision. (See Miller, this volume.)

18.9 Hurricane levee. We are entering an area of less completely drained swamp, which will be used for expansion of New Orleans East. Already the interstate highway has interchanges which dead end in the mire. The area is protected from flooding by a series of levees that surround it.

20.7 Lake Pontchartrain bridge and junction U. S. 11. Proceed on Interstate 10 towards Slidell. The bridge for U. S. 11 can be seen on the left hand side of the vehicle.

23.5 Enter St. Tammany Parish.

24.9 Crest of the large craft passage (high rise). From this point the upland, which represents the Pleistocene Prairie Terrace, can be seen directly ahead. The well-drained nature of the Prairie sediments is indicated by the large stands of pine trees. The Prairie Terrace is correlative with the Pamlico surface in Mississippi and Alabama (see below). The fringing, brackish water marsh of the lake can also be seen from this vantage point.

26.2 End of the Lake Pontchartrain bridge. The marsh lands adjacent to the bridge landing have been drained and are now protected from flooding by levees.

28.4 Scarp of the Prairie Terrace. Interstate 10 rests on this terrace in this portion of Mississippi, except where present day rivers have deposited alluvium.

29.3 Junction 433 — Slidell exit. Proceed east on Interstate 10.

30.2 Borrow pit on the right side of the interstate. Exposed are mottled, buff-colored clays of soil horizon developed on the Prairie Terrace.

33.2 Junction I-12, and I-59. Proceed east on Interstate 10 towards Bay St. Louis.

35.6 Cross West Pearl River and entering Pearl River floodplain (cypress-tupelo swamp).

39.6 At the crest of the Pearl River draw bridge the Louisiana state line is crossed. Enter Hancock County, Mississippi.

40.3 Re-enter pine forest of the Prairie Terrace.

42.4 On the left side of the interstate in the distance can be seen the engine test towers of the Mississippi Test Facility (NASA).
54.8 Jourdan River. Note the undisturbed marsh.
58.6 Enter Harrison County, Mississippi.
67.4 Wolf River.
78.5 Enter floodplain of the Biloxi River.
79.4 Biloxi River.
83.5 Tchoutacabouffa River.
84.1 Leave I-10 at exit 44 (Cedar Lake Road) and proceed south towards Biloxi.
84.7 Traffic light. Turn left on Popps Ferry Road.
Now driving along Big Ridge. This feature has variously been designated as an old shoreline (Pamlico) or attributed a tectonic origin (fault). The authors favor the former hypothesis because of its continuity with other similar features at the same elevation in Alabama and Florida.
86.0 STOP 1 — Good view of Big Ridge escarpment looking down on Rolling Hills trailer park. A nearly identical feature, with similar relief, will be seen just north of Bayou La Batre, Alabama.
86.8 Continue east on Popps Ferry Road to intersection with Highway 67. Turn right on Highway 67.
87.4 Turn right on service road just before Interstate 110 overpass.
87.9 Turn left on Rodriguez Street and proceed to I-110 north entrance.
88.1 Turn left on I-110.

89.4 Continue north on I-110 to I-10 interchange (Exit 4A, east), and proceed east on I-10 toward Mobile, Alabama.

90.4 Jackson County Line.
106.7 Western edge of Pascagoula River tidal marsh.
120.3 Alabama State Line.
124.5 Leave I-10 at Dawes-Grand Bay exit. Turn right toward Grand Bay on County Highway 11.
125.8 Intersection with U. S. Highway 90. Turn right on U. S. 90. (Elevation = 120 feet.)
125.9 Intersection with State Highway 188 in Grand Bay. Turn left on Highway 188. Cross railroad tracks and turn right parallel to tracks for 0.2 miles. Turn left and continue 0.3 miles to intersection. (Elevation = 97 feet.) Turn left.

126.9 Three and one-half miles south on road entering on left is an excellent exposure of the Pamlico terrace escarpment—similar to that seen at the stop on Big Ridge. Citronelle Formation sediments are also in visible contact with the younger terrace sands at this location.
131.6 Siderite nodules in road cuts. Now driving on Wicomico Terrace (Third Terrace of Harvey and Nichols, 1960).
132.2 Edge of Third Terrace. (Elevation = 85 feet.) Drop down onto Second Terrace (Penholoway).
133.1 Intersection with State Highway 39. Intersection lies at the top of an escarpment that forms the southern margin of the Second Terrace. Erosional plain of the First Terrace (Pamlico) is visible at bottom of hill and continues southward toward the coast.
Turn left on Highway 39 and proceed north.
134.6 STOP 2 — "Dirt Incorporated." This stop provides an excellent exposure of both the Citronelle Sand and Ecor Rouge Sand. Most of the criteria that are discussed in the text that serve to distinguish the two units may be seen at this stop. Note especially the numerous ironstone pebbles that are characteristic for Citronelle formation throughout Mobile and Baldwin counties.
Leave pit and turn left on Highway 39.
139.1 Intersection with U. S. Highway 90. (Elevation = 130 feet.) Turn right on Highway 90. Now driving on Third Terrace (Wicomico).
142.4 Descend hill underlain by Miocene sands. (Elevation at bottom of hill approximately 100 feet.)
143.6 Cross Bellingrath Road.
144.2 Turn right on Hamilton Road (National Butane on right at intersection).
145.0 Pit owned by Counts Construction Company. (Elevation = 45 feet.)
The town of Theodore is located on terrace sands that are fluvial and estuarine in origin. Extending southward for approximately 10 miles (see diagram in text) is a sequence of clean, white, cross-bedded sands that evidence a Pleistocene-age, curvilinear marine bar. The bar has a maximum width of one mile and was considered by Carlston (1950) to be Penholoway in age.
STOP 3 — The upper part of this bar is exposed in the pit and the sediments are noticeably dissimilar to Citronelle, Ecor Rouge, and non-marine terrace deposits that will be seen the remainder of the trip. The existence of this marine feature argues against those claiming that no Pleistocene deposits of marine origin are present in the Gulf Coast at elevations greater than 10 meters.

147.8 Pass under Interstate Highway 10. Now driving on dissected surface of Second Terrace.

149.6 Large quarry behind Stacy Lumber Company (on right) has exposure of 40 feet of Miocene sands and clays of the Ecor Rouge Formation.

150.6 Turn left on Demetropolis Road (at traffic light). Now climbing onto Citronelle surface. Miocene sediments exposed in ditches as hill is ascended. (Intersection elevation = 45 feet.).

152.8 Turn left on Cottage Hill Road. (Elevation = 180 feet.)

153.0 Turn right onto University Boulevard. Citronelle sands exposed in cuts along road.

155.2 Cross Airport Blvd.

156.2 Cross Old Shell Road.

156.5 Campus of the University of South Alabama on left. (Elevation = 185 feet.)

157.7 Municipal Park on right. Note extensive tree damage from Hurricane Fredrick (1980) and flooding (1981).

158.2 Cross Ziegler Blvd. University Blvd. now becomes Forest Dale Drive.

158.8 Turn right on Overlook Drive.

159.2 Intersection with Moffat Road (U. S. Highway 98). (Elevation = 203 feet.) Continue east on Moffat Road.

159.3 Traffic light (Mobile Waterworks on left).

159.4 Traffic light

160.3 Turn left onto Wolf Ridge Road at next traffic light. (Elevation = 120 feet.)

161.4 Mobile-Prichard city limits.

162.2 STOP 4 — Sand and gravel pit located on east side of road. A section of approximately 35 feet is exposed on the east face of this pit. A large cut-and-fill structure is visible and consists of deeply weathered channel sands of the Citronelle Formation overlying the Miocene Ecor Rouge Sand. A number of sites are present where well developed Leisegang Banding may be seen in the Miocene sands.
Return to Wolf Ridge Road. Turn right and continue north to intersection of U. S. Highway 45.

163.2 Turn left (west) on Highway 45. (Elevation = 45 feet.)

164.4 Cross Shelton Beach Road (3rd traffic light).

167.0 Kushla.

167.7 Cross Highway 185.

168.2 Reddish-brown sands of the Citronelle Formation exposed in ditch on right side of road.

170.2 Enter town of Mauvilla.

171.2 Citronelle sands exposed in large quarry on left side of road.

171.4 Turn right on Kali Oka Road and proceed 0.2 miles. Turn right on dirt road and proceed to house at end of road. Drive past house and turn left across small dam. Continued driving from here depends on condition of road. Follow road down to railroad tracks and cross tracks. Exposure is located in bend of Chickasabogue Creek. (Elevation of creek = 30 feet.)
STOP 5 — Approximately 7 feet of dark gray, bedded sandy clays are exposed above creek level. These sediments form a slight angular unconformity with the horizontal Citronelle sands that overlie them. The vertebrate fossils are found in a bed located about three feet above present water level.
Return to paved road and turn left (back to Highway 45).

171.8 Turn right on Highway 45. (Elevation = 175 feet.)

172.3 Dirt road on left side of Highway 45. Citronelle sands exposed along dirt road.

173.3 Miocene clays on left side of road.

173.6 Mottled Miocene clays exposed in ditch on left side of road.

173.9 Lavender and green Miocene clays exposed in ditch on left side of road.

174.1 Miocene clays exposed intermittently for next 1/4th mile.

174.9 Citronelle sands exposed on right side of road. At top of hill on left side of road is another cut-and-fill structure of Citronelle sands cut down into the Miocene clays.

175.7 Miocene clays exposed on left side of road.

176.1 Citronelle sands exposed at top of hill.

177.0 Entering Chunchula. (B.M. = 112 feet.)

177.4 Crossing Georgetown Road.

177.3 Miocene clays exposed on left side of road.

181.5 Road to left leads to Chunchula landfill; Citronelle sands exposed on left at top of hill.

181.8 Bridge.

183.2 Miocene sands and clays exposed on left side of road.

184.1 Climb onto old Citronelle erosional surface.

184.7 Citronelle sands exposed on road on left.

186.5 Drive along old Citronelle erosional surface (elevation 300 feet). Citronelle sands exposed along road and in ditches.

187.7 City limits of Citronelle, Alabama. (Elevation = 310 feet.)
188.7 Turn right on paved road that angles off to the center of Citronelle.
190.3 Traffic light in downtown Citronelle. Continue straight ahead on Coy Smith Highway.
190.6 Immediately past railroad overpass, turn left on paved road.
190.9 Paved road ends and becomes a dirt road. Continue on dirt road 0.1 mile to type section of Citronelle Formation.
STOP 6 — Two to three feet of deeply weathered reddish-brown sands are present at the top of this exposure, underlain, successively, by five feet of massive gray clay and four feet of reddish-brown, structureless, sand. The actual type section described by Matson (1916) was probably located about 100 yards to the east along the old railroad cut.
Return to Coy Smith Highway.
191.3 Turn left on Coy Smith Highway (State Highway 96). Citronelle sands are exposed in a number of cuts along this road.
192.7 Storage tank farm on left side of road. Oil here is pumpted from Cretaceous Tuscaloosa Formation at depth of approximately 10,000 feet.
192.9 Fifteen feet of Citronelle sands exposed in quarry on right side of road. The deeply weathered, reddish-brown sands at this site occur as a channel deposit incised into bedded Miocene sands and clays.
193.7 Exposure of bedded Miocene clays approximately 100 yards off highway on left side of road.
194.8 Miocene clays, sand, and intra-formational ironstones on left side of road. Note characteristic "brassy" yellow color of the Miocene sands at this site.
196.4 Miocene sediments exposed on left side of road.
196.9 Citronelle channel sands on right side of road.
199.2 Cemetery on left.
200.9 Citronelle sands exposed in small ravine on right side of road.
201.5 Citronelle sands on both sides of road.
202.5 Possible Citronelle-Miocene contact on left side of road.
202.8 Miocene sands on left side of road.
203.9 Miocene sands on both sides of road.
205.1 Searcy Hospital on right.
205.5 Dropping down onto western side of Mobile River flood plain.
205.7 Railroad tracks. (B.M. = 48 feet.)
205.8 Intersection with U. S. Highway 43. Turn left on Highway 43. Intermittent exposures of Miocene clays, Citronelle colluvium and recent allumvium are present along highway, which lies about 3 miles west of the present river channel.
206.8 Railroad crossing. (Elevation = 50 feet.)
208.6 Large exposure of Miocene clays on right side of road.
210.1 Calvert.
210.7 Washington County Line.
211.1 Bridge.
211.2 Bridge.
212.9 Malcolm city limits. Terrace sands(?) on right side of road. (Elevation = 50 feet.)
214.3 Bridge (Bates Creek).
216.4 Bridge (Bilbo Creek).
217.4 MacIntosh city limits. (B.M. = 48 feet.)
218.4 County Highway 35 on left.
218.7 MacIntosh Bluff historical marker: "Here in 1807 ex-Vice-President Aaron Burr was arrested and sent on horseback via Fort Stoddart to Richmond where he was tried for treason and acquitted".
223.5 Bridge.
226.1 Sunflower. (B.M. = 67 feet.)
227.0 Orange brown terrace sand(?) exposed intermittently for the next mile.
229.1 Rest-area turn-off.
230.0 Miocene clays on both side of road. Terrace sands occurs as channels in the clays at several sites at this exposure.
230.8 Wagarville.
231.2 State Highway 56 on left to Chatom, Alabama. (Elevation = 66 feet.)
231.5 Mottled terrace(?) sands on right side of road.
232.1 Miocene sands on left side of road.
232.7 Bridge (Bassetts Creek).
233.0 Miocene sands and gravels on left side of road.
233.2 Miocene sands on left side of road.
234.2 Large exposure of Miocene sands and gravels exposed in quarry on left side of road.
STOP 7 — The sands and gravels exposed in this pit represent a coarse, fluvial phase of the Miocene that is only locally developed. These coarse clastics will be seen again at Jackson, Alabama, where they are disconformably overlain by younger terrace deposits.
236.3 Turn-off to St. Stephens (former State Capitol of Alabama). A large quarry is located on the Tombigbee River at St. Stephens where an excellent section of Eocene and Oligocene limestones and clays are exposed.

238.7 Begin descent to Tombigbee River flood plain. Miocene sands and gravels are exposed intermittently along the road.
239.7 Southern edge of Tombigbee River flood plain.
239.7 Bridge. A large quarry can be seen off to the right at the top of the hill which contains an excellent exposure of upper Miocene coarse clastics.
240.7 Highway 177 turns off to right. Miocene sands and gravels are exposed, continuously, along both sides of the road as the hill is climbed.
241.4 Contact of Miocene coarse clastics with terrace sands.
241.1 State Highway 69 turns off to left.
242.4 Miocene sediments exposed on right side of road.
242.8 Thirty feet of Miocene sands are exposed in a cut on the left side of the road. The upthrown side of the Jackson Fault has just been crossed.
243.3 Terrace sands exposed on top of hill.
243.8 Contact of terrace and Miocene sediments exposed on right side of road.
244.7 Beverly Lane turn-off to Little Stave Creek on left.
245.2 West Point Drive turn-off to Little Stave Creek on left.
245.6 Terrace sands exposed at top of hill.
246.8 Contact of terrace and Miocene deposits.
247.3 STOP 8 — Miocene sands at this location form an angular unconformity with overlying terrace sands. Faulting is a consequence movement along the nearby Jackson Fault.
Turn around and return to Jackson, Alabama.
250.8 Downtown Inn Motel.

END OF ROAD LOG FOR FIRST DAY.

ROAD LOG
SECOND DAY OF FIELD TRIP

250.8 Downtown Inn Motel. Proceed south on Highway 43 and turn right at intersection of Highway 69. Miocene sands exposed on right side of road. (Elevation = 190 feet.)
251.1 Terrace sands crop out on both sides of road.
Jackson Academy. Terrace sands exposed in cut behind football field. (Elevation = 240 feet.)
252.2 Terrace sands exposed on both sides of road.
252.7 Miocene sands present on both sides of road. Dropping down into valley of Stave Creek.
253.1 Marianna Limestone (Oligocene) exposed on right side of road.
253.3 Stave Creek Bridge.
253.6 Miocene sands on right side of road.
255.6 Terrace sands on right side of road.
256.0 Lisbon Formation (Eocene) exposed in cut behind house.
256.7 Tallahatta Formation (Eocene) exposed on right side of road.
256.8 Historical marker: "Upper saltworks. The area from Stave Creek to Jackson Creek was one of the sites for the making of salt during the years 1862-64. Furnaces of native stone were built and saltwater from dug wells evaporated by boiling in large kettles. Amount of salt 600 bushels per day. Price, $10-$40 per bushel. Workers were exempt from military service."
The source of these waters is reported as derived from saline waters rising from the Cretaceous Tuscaloosa Formation(?) along the Jackson Fault and is, therefore, not believed associated with salt dome activity in the area.
256.9 Tallahatta Formation exposed on right side of road.
257.2 Weathered Hatchetigbee sediments exposed on both sides of road.
257.5 Cross Jackson Creek.
257.7 Bridge. (Elevation = 40 feet.)
258.4 Clays of the Hachetigbee Formation exposed in ditches on both sides of road.
258.5 Terrace sands on both sides of road. Driving along crest of Hatchetigbee Anticline for next 3 miles.
258.8 Terrace sands on left side of road in road cut and ditch.
259.6 Road to left leads to old lock #1 on Tombigbee River.
260.2 Cuts on right side of road expose terrace sands.
261.0 Salitpa. (Elevation = 184 feet.)
262.4 Weathered Hatchetigbee clays exposed on side of road.
263.1 Terrace sands on both sides of road. Descending through the Hatchetigbee Formation, which is largely covered.
263.7 Bridge (Kanetuche Creek).
264.0 Terrace sands at top of hill on right side of road.
264.8 Terrace sands in cut on right side of road.
265.2 Tallahatta Formation exposed on right side of road.
265.8 Terrace sands with lenses of fine to medium gravel.

266.6 STOP 9 — The road cut on the right reveals a sequence of approximately 6 feet of green to bluish-green clays from the Tallahatta Formation overlain by 12 feet of brown sands, clays and sandstones, belonging to the Lisbon Formation. These are, in turn, overlain by 4 to 5 feet of reddish-brown, terrace sands.

267.0 Exposure of Tallahatta, Lisbon, and terrace sands on right side of road.

267.6 Bridge (Satilpa Creek).

267.8 Bridge.

268.2 Tallahatta exposed on right side of road.

268.7 Terrace sands on both sides of road.

269.5 Terrace sands exposed in cut on right side of road. Begin descent into Valley of Eberline Mill Creek.

269.8 Bridge.

270.2 Terrace sands in cut on left side of road.

270.5 Terrace sands in cut on right side of road.

271.0 Large exposure of terrace sands.

272.0 Coffeeville city limits. (Elevation = 180 feet.)

272.9 Intersection with U. S. Highway 84. Turn left onto Highway 84 toward Silas.

273.2 Highway 69 turns off to right. Continue on Highway 84 (west).

273.6 Terrace sands exposed in cuts on both sides of road. Beginning descent into Tombigbee River valley.

273.8 Choctaw County Line.

274.0 Big Jim Folsom Bridge across Tombigbee River.

274.1 Tombigbee River floodplain. Sediments consist of recent alluvium.

275.9 Bridge.

276.3 Western edge of Tombigbee River floodplain. Tallahatta, Lisbon, and terrace sediments exposed in cuts on both sides of road.

276.6 Choctaw County Highway 6 on left. Turn left on County Highway 6. (Elevation = 120 feet.)

STOP 10 — A large cut-and-fill structure is apparent here with terrace sands filling a channel that has been cut down through the Lisbon Formation, into the Tallahatta Formation.

Turn around and return to Highway 84.

276.8 Turn left on Highway 84.

276.9 STOP 11 — Large cuts on right side of road shows excellent exposure of Tallahatta overlain by Lisbon sediments. The Lisbon is, in turn, overlain by terrace sands.

A number of exposures of the Tallahatta Formation will be seen in road cuts for the next few miles. The red sands that are seen disconformably overlying the Tallahatta clays, and claystones, have been mapped as belonging to the Lisbon Formation.

280.9 Tallahatta sediments on right side of road.

282.6 Bridge.

282.8 Turn right on Choctaw County Highway 21.

283.8 Reddish-brown sands of the Lisbon Formation on right side of road.

285.7 Fossiliferous, gray, clays and sandy clays (Lisbon) exposed in cut on left side of road. Upper sands appear to disconformably overlie these clays.

286.9 Turn left at intersection (west) toward Gilbertown.

289.4 Lisbon clays on right side of road.

290.5 Oil well on right side of road. This well is located in the Gilbertown Field which was originally discovered in 1944. As such, it represents the oldest field in Alabama. Production is currently derived from the Selma and Eutaw Formations at depths of approximately 3,500 feet.

292.6 Enter Gilbertown. Highway 17 junction. Turn left on Highway 17 and proceed south.

295.3 STOP 12 — Quarry on right side of road reveals an excellent exposure of 30 to 40 feet of Lisbon sediments. The variability in lithology found in the upper part of the Lisbon may be well seen at this site.

296.6 Tallahatta clays and claystones on left side of road.

299.7 Cross U. S. Highway 84 in Silas, Alabama.

305.8 Washington County Line.

308.8 Millry city limit.

A number of exposures of Miocene sands and clays will be seen on the highway between Millry and Chatom.

321.0 Chatom city limit.

338.3 Junction with U. S. Highway 45. Continue south on Highway 45.

347.0 Mobile County Line. (Citronelle city limits).

350.6 Traffic light in Citronelle. Continue south on Highway 45 to Interstate Highway 10, in Mobile. Return to New Orleans via Interstate 10.

END OF ROAD LOG.

DR. CHARLES RUDOLPH KOLB (1920-1982): A DEDICATION

This issue of *Tulane Studies in Geology and Paleontology* is dedicated to the memory of Dr. Charles R. Kolb, who was well known to those of us interested in the Quaternary stratigraphy and geologic history of Louisiana and Mississippi. His compilations of subsurface stratigraphic information, publications on deltaic and fluvial processes, and engineering geology reports represent a significant body of contributions to the study of the geology of the southeastern United States. Dr. Kolb's interests were broad and his manner was inspiring; those who love Coastal Plain geology will feel his loss acutely. Dr. Kolb died in Vicksburg, Mississippi, on 26 November, 1982.

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STRATIGRAPHY OF NEWLY EXPOSED QUATERNARY SEDIMENTS, EASTERN ORLEANS PARISH, LOUISIANA

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I. ABSTRACT

Five Late Quaternary stratigraphic units are exposed at the Lake Carmel borrow pit in eastern Orleans Parish. These are, in ascending order: 1) deltaic equivalents of Deweyville terrace alluvium (Wisconsin); 2) a buried soil zone, herein informally named "Little Woods paleosol" (late Wisconsin-early Holocene); 3) bay-sound clay, herein formally designated the "Michoud Formation" (middle Holocene); 4) barrier bar sand of the New Orleans trend (middle Holocene); and 5) St. Bernard prodeltaic and delta front deposits (late Holocene). This succession of beds records the environmental history of the vicinity of the borrow pit as the following sequence of major events: 1) the emergence of a late Pleistocene delta lobe and pedogenic alteration of deltaic deposits; 2) the subsequent inundation of the southern Lake Pontchartrain and New Orleans area by transgressive Gulf waters forming the Pontchartrain Embayment; 3) progradation of the New Orleans barrier trend across the mouth of the embayment; and finally, 4) encroachment of a St. Bernard delta lobe on the New Orleans trend and eventual isolation of the embayment from the Gulf of Mexico to form the present Lake Pontchartrain.

II. INTRODUCTION

Although thousands of borings and temporary excavations of various kinds have penetrated the Holocene and late Pleistocene sediments beneath the New Orleans area, surface exposures of these deposits essentially do not exist. For the most part, stratigraphic information on these shallow subsurface deposits has come from borings that were originally used to collect data for engineering projects (*e.g.*, Saucier, 1963; Kolb *et al.*, 1975); paleontologic information has come mainly from a few temporary excavations and spoil piles in the area associated with road and canal construction (*e.g.*, Rowett, 1957; DeWindt, 1974; Hollander and Dockery, 1977). Likewise, information used to reconstruct the Quaternary history of the Mississippi Delta has necessarily come from subsurface borings (*e.g.*, Fisk and McFarlan, 1955; Coleman and Gagliano, 1964; Kolb and van Lopik, 1966; Frazier, 1967). In a region where surface elevations are at or just below sea level, borrow pit exposures represent extremely

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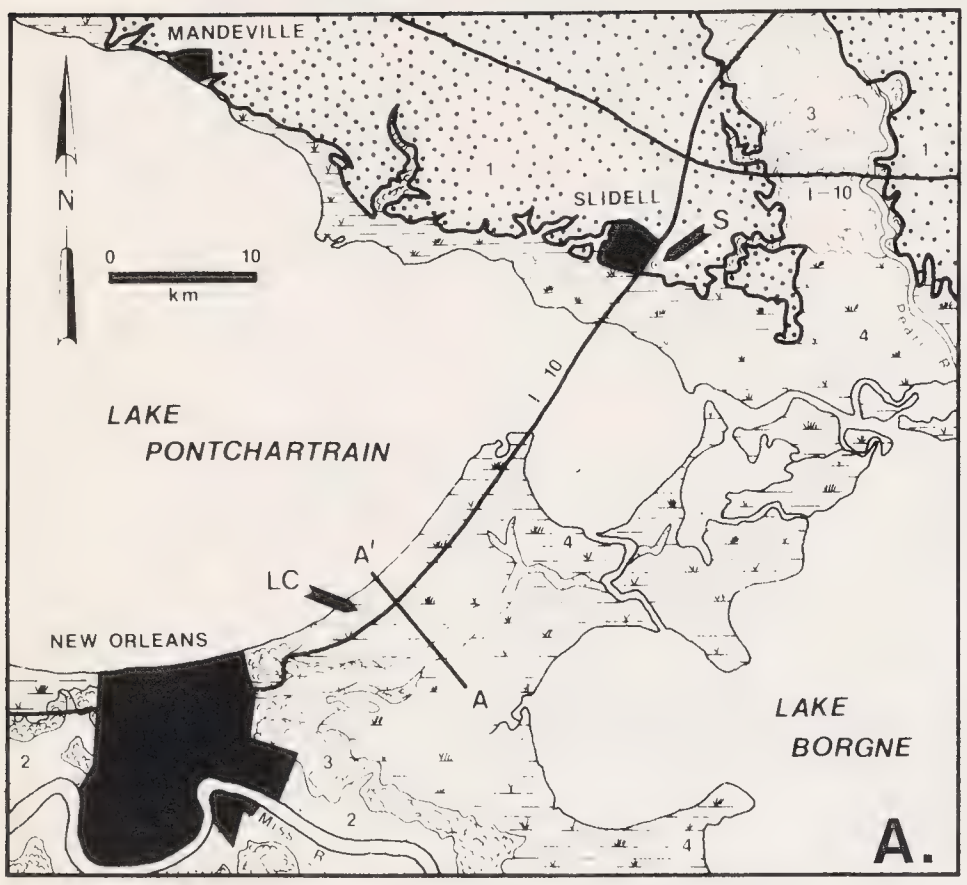

Fig. 1. Index map and general stratigraphy of eastern Orleans Parish. A, Location of Lake Carmel Borrow pit (LC). Symbols have the following meanings: 1 = Prairie Terrace, 2 = natural levee, 3 = backlevee swamp, 4 = marsh, S = borrow pit near Slidell with exposure of Prairie Formation. B, Cross-section showing formational units in eastern Orleans Parish, including: Pp = Pleistocene Prairie Formation; Pd = Pleistocene Deweyville equivalents; Pds = large sand body within the Deweyville beneath the south shore of Lake Pontchartrain; Hm = Holocene Michoud Formation (new name used herein); Hsb = Holocene St. Bernard deltaic blanket; and Hsm = Holocene swamp and marsh surface deposits. (See text for explanation of stratigraphic relationships. Map and cross-section after Saucier, 1963, Figs. 7 and 18, with modifications.)

important opportunities to study lithostratigraphic units that are usually only known from borings (*e.g.*, Otvos, 1978).

In 1980 and 1981, I had the opportunity to study an extraordinary 12 m vertical exposure of Quaternary deposits in eastern Orleans Parish, about 16 km from downtown New Orleans. The purpose of this report is to describe the lithostratigraphy of the Lake Carmel borrow pit, and to use well-exposed physical and biogenic sedimentary structures, textures, sequence of units, and fossils to reconstruct the late Pleistocene to Holocene environmental history of the area. In addition, I describe for the first time in detail the nature of the Pleistocene-Holocene contact in the New Orleans East area, propose two new stratigraphic unit names, and list over 140 fossils from the exposure.

III. ACKNOWLEDGMENTS

I wish to acknowledge the invaluable assistance provided by the late Dr. Charles R. Kolb in the preparation of this paper. Dr. Kolb encouraged my work, and provided critical information on local stratigraphy and allowed the use of radiocarbon dates obtained at the Lake Carmel pit.

Drs. Harold E. and Emily H. Vokes accompanied me in the field and provided the excellent photographs. Mr. George Mollyn identified the fossil mollusks listed in the Appendix. Mr. Nelson Chatelain, owner of the property on which the pit is located, gave permission to work at the site. The manuscript was carefully reviewed by Drs. Jules R. DuBar, Ervin G. Otvos, and Jesse O. Snowden, but I remain solely responsible for all observations, conclusions, and speculations embodied in the final version.

IV. LOCALITY AND METHODS

The Lake Carmel pit is located in an area of reclaimed wetland, between Lake Carmel housing development on the east and Jahncke Canal to the west, 0.5 km northeast of the junction of Bullard Avenue and U. S. Interstate Highway 10 on the outskirts of New Orleans (Fig. 1, A). Surface elevations in the vicinity of the pit average −1.5 to −2 m, and the deepest areas of excavation are about 15 m below mean sea level (13 m below the surrounding land surface). Surface deposits in the area consist of Recent marsh peats and organic muds, which are described in several reports on the environmental geology of the Mississippi deltaic plain in the environs of New Orleans (see Saucier, 1963; Kolb and van Lopik, 1966; Bankey, 1980; Snowden *et al.*, 1980).

The borrow pit was visited at irregular intervals during 1981 to measure the sec-

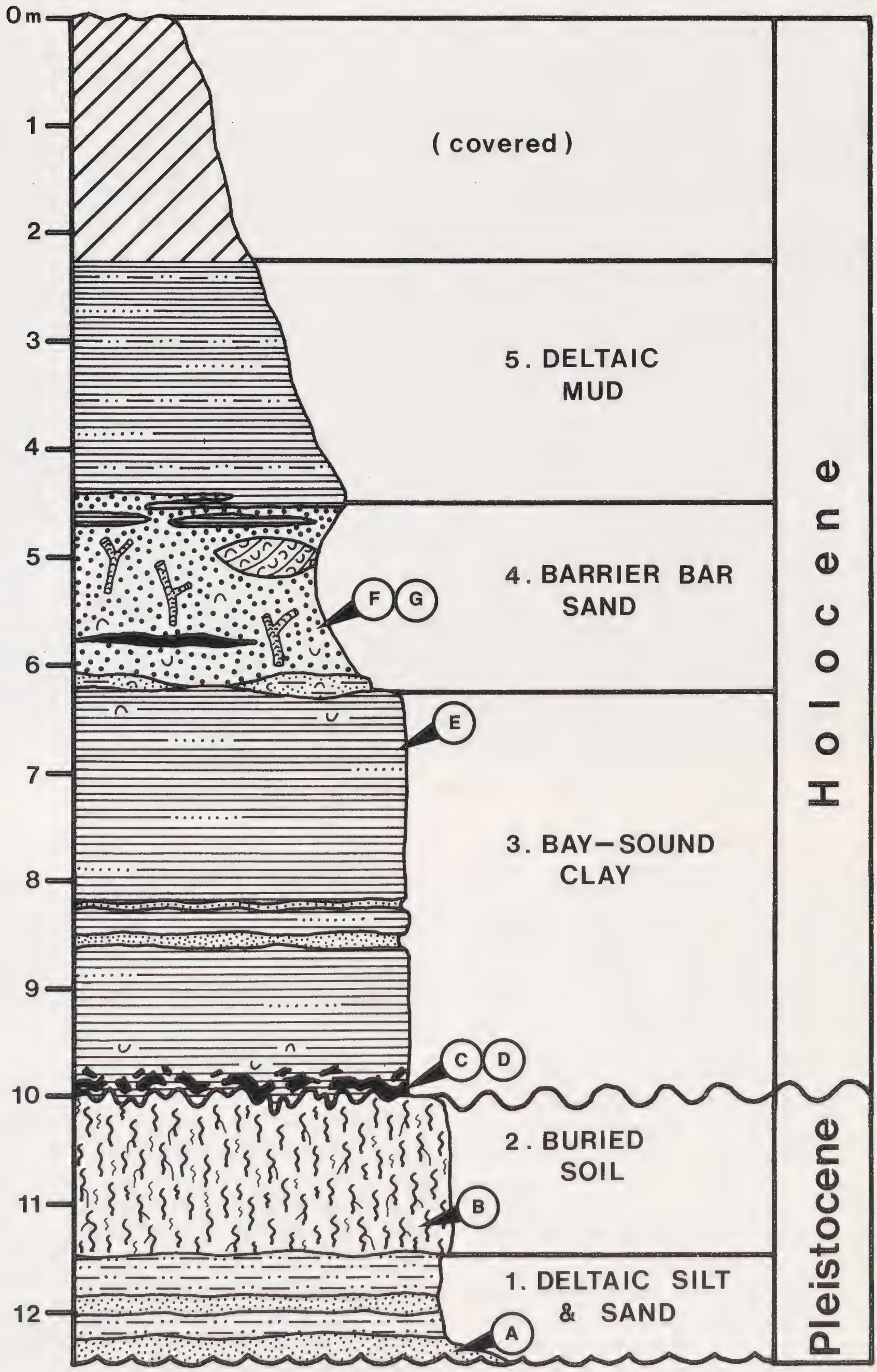

Fig. 2. Composite columnar section of the Lake Carmel borrow pit. Lithostratigraphic unit numbers correspond to unit numbers in Table 1. Circled letters are sample locations for radiocarbon dates: A, 31,270± 370 years B.P.; B, 7,690± 70 years B.P.; C, 7,290± 80 years B.P.; D, 7,200± 50 years B.P.; E, 4,290± 50 years B.P.; F, 11,090± 90 years B.P.; G, 29,860± 430 years B.P. Radiocarbon dates are discussed in the text and Table 2.

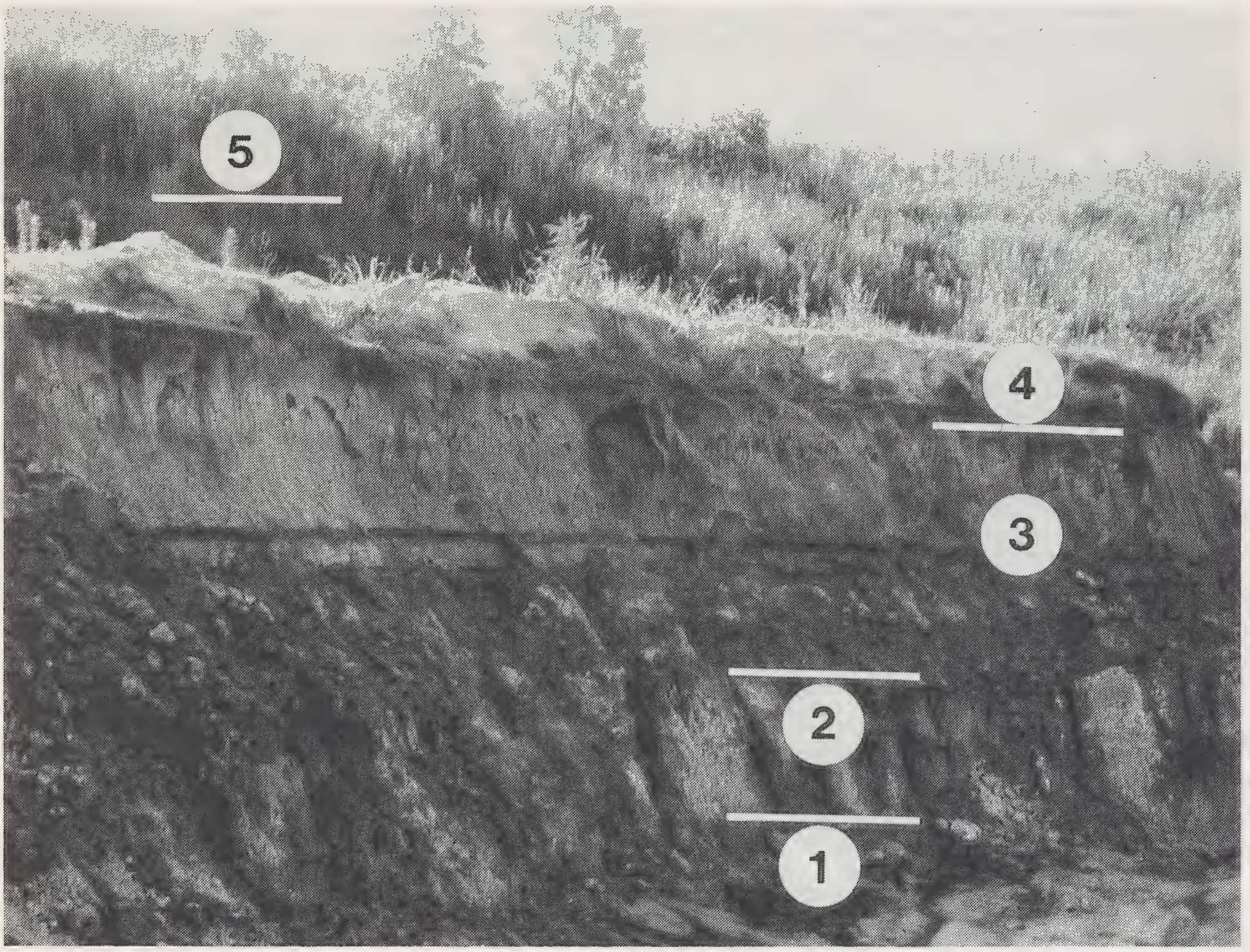

Fig. 3. Northeast wall of Lake Carmel pit, as it appeared in June, 1981. Unit numbers correspond to those used in Fig. 2 and Table 1.

tions exposed in the walls of the pit, to record information on sedimentary structures, and to make collections of fossils. Photographs and detailed sketches of contacts and structures were made, and bulk samples of fossiliferous intervals were collected and later wet-sieved to remove all identifiable fossils. Fossil collections were supplemented by hand-picking specimens from spoil piles, and organism-substrate relations were assessed by observing fossils *in situ* within entombing sediments. Lithostratigraphic units and the Pleistocene-Holocene contact exposed in the pit were traced into the surrounding area using published compilations of bore hole data (Saucier, 1963; Frazier, 1967; Kolb *et al.*, 1975). Lastly, the environmental history of the deposits was deduced by first comparing the sedimentologic and paleobiologic characteristics of units in the pit with published descriptions of modern and ancient depositional sedimentary environments (Shepard, 1962; Kolb and van Lopik, 1966; Frazier, 1967; Katuna and Ingram, 1974; Reineck and Singh, 1975; Friedman and Sanders, 1978; Reading, 1978; Walker, 1979; Howard and Frey, 1980), and then ordering the identified facies in vertical succession.

V. STRATIGRAPHIC FRAMEWORK

The stratigraphic section exposed in the Lake Carmel borrow pit is divisible into five formational units (Figs. 2, 3). The sequence of units is broken by a major unconformity near the base of the section (Fig. 4), which separates Pleistocene from overlying Holocene sediments in the New Orleans-Lake Pontchartrain region. Lithostratigraphic units identified at the pit are listed and described in Table 1. These units, including a new lithostratigraphic unit and new soil-stratigraphic unit, are discussed below in ascending order, starting at the base of the exposure.

Fig. 4. Pleistocene-Holocene contact exposed in southwestern wall of borrow pit. Contact is an angular unconformity separating light-colored Little Woods paleosol (below) from dark-colored Michoud Formation (above). Man, to left, provides scale.

Pleistocene Sediments
(Deweyville Terrace Equivalents)*

The deepest parts of the pit expose the top of a Pleistocene unit of unknown total thickness that appears to represent a deltaic facies of the Deweyville Terrace (see Flint, 1971, p. 557). These sediments consist of an interbedded sequence of slightly indurated, greenish silts and micaceous sands containing occasional fragments of fossil wood. Pleistocene sediments encountered in subsurface borings directly beneath Holocene deposits in the New Orleans area traditionally have been assigned to the Sangamon Prairie Terrace (see Saucier, 1963; Hollander and Dockery, 1977; Snowden *et al.*, 1980). Recently, however, Kolb *et al.* (1975, p. 3-5, Plate 2) suggested that the downslope deltaic equivalents of the Wisconsin Deweyville Terrace in the Pearl River valley could possibly be found directly beneath the Holocene sediments in the vicinity of Lake Pontchartrain. Prairie equivalents might occur in the area,

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*The river-valley and coastwise terraces of southern Louisiana are morphostratigraphic units like the terraces of the southern Atlantic Coastal Plain. However, the Atlantic Coastal Plain terraces have been intensively restudied, with the result that older terrace-formation terminology is currently being replaced by more conventional lithostratigraphic nomenclature (*e.g.*, Oaks and DuBar, 1974). The detailed reevaluation and clarification of Louisiana terrace-formation stratigraphy has not yet begun, so that the traditional morphostratigraphic designation "terrace" must be retained here to mean what it has always meant in this context — either the morphologic feature, the underlying sediments associated with that feature, or both. When the Deweyville, Prairie, and Montgomery Terraces are restudied, it is likely that this morphostratigraphic terminology also will be replaced by new formation names based on the careful delineation of lithologic units, with carefully described type and reference sections, and mapped using lithologic rather than geomorphic criteria.

but at a greater depth than previously recognized owing to vertical displacement along late Pleistocene faults. The Pleistocene sediments at the base of the borrow pit section are tentatively equated here to the Deweyville based on stratigraphic position and on a radiocarbon date on woody material of 31,270± 370 years B.P. (Charles R. Kolb, person. comm., 1981), which is very close to the time interval when Deweyville Terrace deposits are believed to have accumulated (*i.e.*, about 17,000 to 30,000 years B.P.; see Flint, 1971; Kolb *et al.*, 1975).

Buried Soil (Little Woods Paleosol)

Pleistocene sediments at the borrow pit are capped by a moderately indurated, bluish-gray, root-mottled mud, which represents an ancient soil B horizon that developed in the top of the Deweyville deposits during a lengthy period of subaerial exposure (Figs. 2, 4). The original soil has been eroded so that only isolated pockets of the friable, silty A horizon remain below the unconformity. A single radiocarbon date, on a fragment of wood (root) near the bottom of this unit (Fig. 2), of 7,690± 70 years B.P. (Charles R. Kolb, person. comm., 1981) indicates that the soil was penetrated by roots and was probably still evolving during the early Holocene. This date is regarded as a "minimum age estimate" for the soil zone (see Geyh *et al.*, 1971); radiocarbon dating of peat from immediately above the soil at the base of the Holocene sequence (Fig. 2) would seem to indicate that the minimum age estimate for the soil is close to the true minimum age of the original solum. Soil forming processes preceded intrusion by the youngest series of roots, however, and may well have commenced in the late Pleistocene. Using the method outlined by Beckmann (1971), it can only be determined that the age of formation and development of the soil is bracketed between the age of the Deweyville sediments and that of the overlying peat (see following section) as determined by radiometric dating.

The soil zone at the top of the Pleistocene sediments is here informally named the "Little Woods paleosol," after the village of Little Woods, Orleans Parish, Louisiana, located northeast of the borrow pit, and the Lake Carmel pit is designated as the type locality. The Little Woods paleosol appears to be widely distributed in the New Orleans

Fig. 5. Close-up view of unconformity showing peat rip-up clasts (arrows) located immediately above the contact.

area between the paleofluves in the buried Pleistocene surface, as indicated by bore hole data (Kolb and van Lopik, 1966; Kolb *et al.*, 1975). The paleosol is truncated by an unconformity that separates the youngest Pleistocene deposits in the area from superjacent Holocene beds (Figs. 4, 5).

Originally, the paleosol may have been a weakly differentiated podzolic soil, which developed in silty surface deposits on an interfluvial plain during the late Pleistocene and early Holocene. The soil featured a thin, friable A_2 horizon overlying a thick, oxidized, clayey B_2 horizon. The B_2 horizon contains large root channelways, reminiscent of tap roots, and abundant rootlet channelways that usually only extend down to a limonite-cemented layer in the top of the underlying silt bed (Table 1). The upper part of this silt bed contains occasional roots and probably was the ancient C horizon associated with the superjacent paleosolum. As suggested by the bluish color of the Little Woods paleosol, the original solum became waterlogged and reduced after the differentiation of horizons (see Simonson, 1954, p. 728-729) when the Holocene transgression reached the New Orleans East area about 7,500 years ago.

Unconformity

The Pleistocene-Holocene contact at the borrow pit is marked by an unconformity that separates the bluish-gray Little Woods

Table 1. Composite stratigraphic section of the Lake Carmel borrow pit. Unit numbers are keyed to Figs. 2 and 3.

UNIT	DESCRIPTION	THICKNESS (in meters)
HOLOCENE		
Covered interval		2.2
Deltaic mud (St. Bernard delta complex)		
5.	Clay, with silt and fine sand interlaminations; sand subangular, moderately sorted; continuous, parallel to wavy laminations and some sand lenses; sand interlaminations become thicker and more frequent proceeding up-section; *Rangia cuneata* shells in upper part; dark greenish-gray (5 B 3/1) where fresh, weathers dark yellowish-brown (10 YR 4/2) with light brown (5 YR 5/6) mottles; top not exposed, bottom intertongues with Unit 4b.	2.0
Barrier bar sand (New Orleans barrier trend)		
4b.	Sand, fine to coarse, subangular, moderately to well-sorted; top 20 to 30 cm with variety of physical sedimentary structures (ripple cross-laminations, trough cross-laminations, shelly lenses, wavy clay laminations), remainder of unit with abundant *Ophiomorpha* and occasional peat and clay interbeds; light gray (N 7.5) where fresh, weathers pinkish-gray (5 YR 8/1) with dark yellowish-orange (10 YR 6/6) mottles; grades downward into either Unit 4a or 3.	1.6
4a.	Clayey sand to sandy clay, shelly; sand fine to medium, subangular, moderately sorted; separated from superjacent sand by *Mercenaria campechiensis* shell pavement encrusted by bryozoans and oysters; dark greenish-gray (5 GY 4/1) where fresh, weathers olive gray (5 Y 4/1); grades downward into Unit 3.	0 to 0.1
Bay-sound clay (Michoud Formation[1])		
3.	Silty clay to clayey silt, with occasional flat sand lenses; sand lenses distorted by burrowing; shelly near the top and bottom, with two very fine to fine, subangular, well-sorted sand beds, 0.08 and 0.12 m thick, in middle of unit; discontinuous layer of peat rip-up clasts at base; sand interbeds medium dark gray (N 4.5), peat clasts brownish-black (5 YR 2/1); clay dark greenish-gray (5 GY 3/1) where fresh, weathers olive gray (5 Y 4/1); rests unconformably on Unit 2.	3.6 to 3.8
Unconformity		
PLEISTOCENE		
Buried soil (Little Woods paleosol[2]; top of Deweyville equivalents)		
2.	Clayey silt to silty clay, slightly sandy, abundant root channelways, some containing original root material; moderately indurated; medium bluish-gray (5 B 6/1) with bluish-gray (5 B 5/1) clay coatings in fissures, weathers yellowish-gray (5 Y 8/1); grades downward into Unit 1d.	1.4
Deltaic silt and sand (unaltered Deweyville)		
1d.	Silt, clayey; parallel laminations, occasionally disrupted by root channelways extending from Unit 2; no fossils; greenish-gray (5 G 6/1); top cemented by limonite crust, bottom grades into Unit 1c.	0.4
1c.	Sand, fine, subangular to subround, well-sorted; parallel laminations; wood fragments; grayish-olive (10 Y 4/2) with moderate olive-brown (5 Y 4/4) mottles; bottom marked by micaceous laminations.	0.2
1b.	Same as Unit 1d, but lacks roots; grades downward into Unit 1a.	0.1 to 0.2
1a.	Sand, fine, subangular to subround, well-sorted; no fossils; olive gray (5 Y 4/2); base not exposed.	0.5+
	TOTAL	12.4

[1]New lithostratigraphic unit, described herein
[2]New soil-stratigraphic unit, described herein

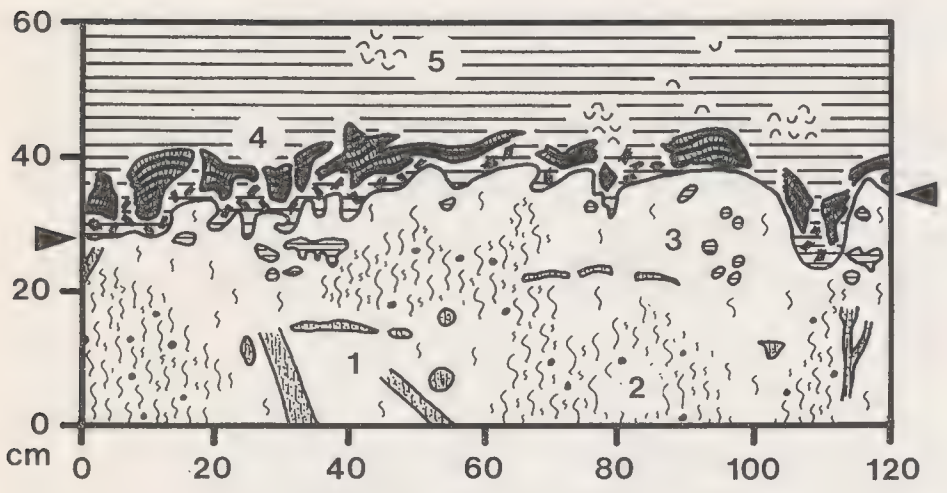

Fig. 6. Sketch of Pleistocene-Holocene contact exposed in south corner of borrow pit. 1, large root channelways filled with light gray (N 5) clay; 2, rootlets and rootlet tubes; 3, burrows and root channelways filled with the superjacent dark greenish-gray (5 GY 3/1) clay; 4, brownish-black (5 YR 2/1), laminated peat rip-up clasts and smaller woody fragments; 5, mollusk shells. Arrows at sides of drawing indicate trace of contact.

paleosol from overlying dark greenish-gray bay-sound clay (Figs. 2, 5). Because the paleosol weathers yellowish-gray and is moderately indurated, the unconformity is easily traced throughout the pit (Fig. 4) and easily identified in subsurface borings (Kolb and van Lopik, 1966; Kolb *et al.*, 1975). Although the unconformity is a very wavy, pitted surface varying in vertical relief by as much as 20 cm over only 40 to 50 cm of outcrop distance (Fig. 6), its average elevation is remarkably uniform at about 10 m below the surrounding land surface in all parts of the pit. Localized depressions in the unconformity may represent old tree-throw pits, as root channelways are often more abundant in the Little Woods paleosol beneath these depressions.

This unconformable contact corresponds to the "First Pleistocene Horizon" in the cross-sections of Kolb *et al.* (1975). Subjacent Pleistocene beds are tilted slightly seaward on a regional scale as a result of subsidence and flexure along growth faults, so the unconformity exposed in the Lake Carmel pit should be regarded as an angular unconformity. In the New Orleans area, the top of the Pleistocene varies in elevation from −10 m on ancient interfluvial plains (which includes the Lake Carmel borrow pit area) to around −40 m in paleochannels and beneath the Mississippi River; the Pleistocene surface is near sea level in the northeastern part of Lake Pontchartrain (Kolb *et al.*, 1975, Plates 2, 5).

Bay-Sound Clay (Michoud Formation)

The oldest Holocene unit in the Lake Carmel pit is the slightly shelly, greenish-gray, soft silty clay to clayey silt immediately above the unconformity. The clay contains occasional flat lenses of sand and two laterally continuous sand beds located near the middle of the unit (Figs. 2, 7). The bottom of the clay contains abundant, brownish-black rip-up clasts of peat (Fig. 6), from which radiocarbon dates of 7,290± 80 and 7,200± 50 years B.P. have been obtained (Charles R. Kolb, person. comm., 1981). These dates mark the time when marshy paralic depositional environments reached the New Orleans East area at the advancing edge of the modern transgression of Gulf waters; adjacent paleofluves were probably flooded at this time and contained subtidal estuarine environments (see Saucier, 1963, p. 42-44). That is, sea level had reached an elevation of about −10 m around 7,300 years ago, and shortly thereafter former interfluvial plains were inundated in the Lake Carmel pit area (Saucier, 1963, Fig. 19). The top of the unit is

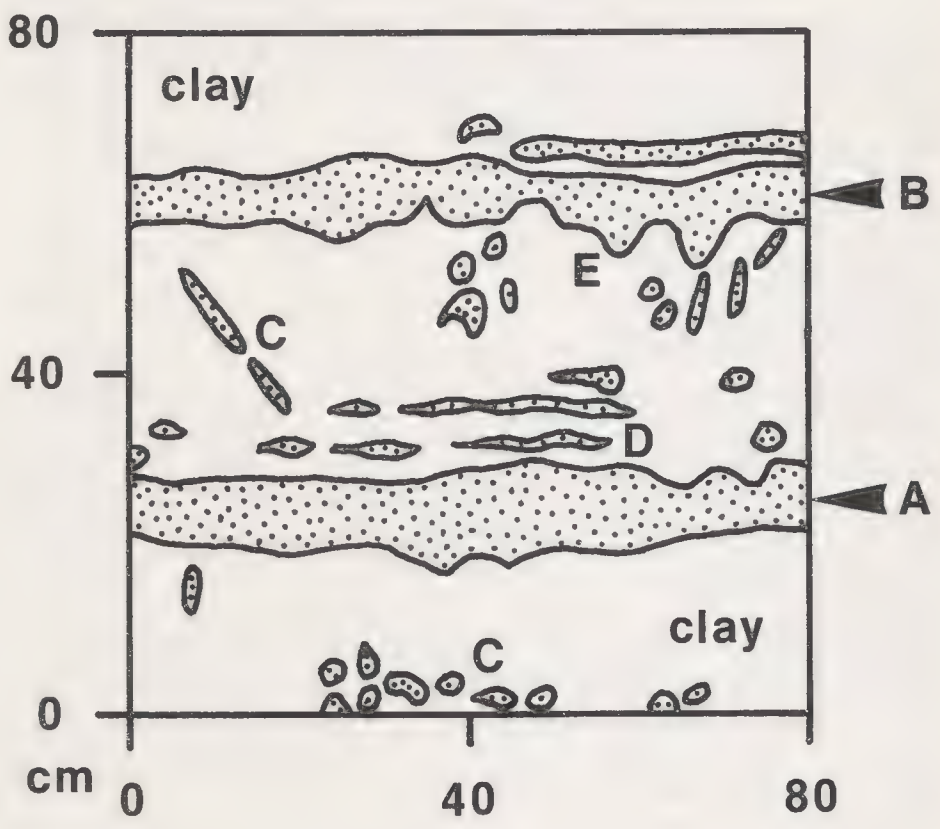

Fig. 7. Detailed sketch of sand interbeds occurring within the Michoud Formation, as exposed in the southeast wall of the pit. A, lower fine sand interbed; B, upper fine sand interbed; C, burrows originating in superjacent sand layers and filled with the sand; D, flat sand ripples surrounded by clay; E, load structures on underside of sand bed, indicating original hydroplastic nature of underlying clay.

an old firm-ground bored by *Petricola pholadiformis, Barnea truncata,* and *Cyrtopleura costata.* A radiocarbon date of 4,270± 50 years B.P. was obtained on a clam shell located just beneath this old firm-ground (see section below).

This clay unit can be traced beneath the city of New Orleans and Lake Pontchartrain in cross-sections published by Saucier (1963, Fig. 18) and Kolb *et al.* (1975, Plates 10, 12a, 12b, 17, 19, 20, 21, 22, 24, 27, 28, 29, 31, 32, 36, and 27). Although the unit has been identified in several studies of shallow subsurface stratigraphy in this area, no formal lithostratigraphic nomenclature has been applied. Therefore, for convenience of reference and emphasis, I propose the name "Michoud Formation" for the generally fine-grained Holocene transgressive deposits (mainly silts and clays with occasional sandy subunits) situated stratigraphically above the regional unconformity at the top of Deweyville deposits and below either Holocene barrier island sands (New Orleans barrier trend; Otvos, 1978) or deltaic deposits associated with the modern Mississippi River. The formation is named for the village of Michoud (pronounced *mē'shü),* Orleans Parish, Louisiana, located just southeast of the borrow pit. The Lake Carmel borrow pit is designated as the type locality and the east wall of the pit is regarded as the type section (Figs. 2, 3). Bore holes 19-8, 19-9, 20-30, 24-1, 81-398, 83-10, 83-16-W, and 89-1 illustrated in Kolb *et al.* (1975) penetrated the Michoud Formation at the bottom of sequences of Holocene sediments, and can be used as reference sections in lieu of additional surface outcrops. The formation includes the nearshore Gulf and bay-sound deposits of Saucier (1963, Fig. 18), bay deposits of Frazier (1967, Fig. 9, north end of section D-D′), and offshore-lower shoreface and bay-sound facies of Hollander and Dockery (1977, Fig. 2). The physical sedimentology of the Michoud Formation has been described by Tagett (1982).

Barrier Bar Sand
(New Orleans Barrier Trend)

The Michoud Formation grades upward into a thin, discontinuous clayey sand containing abundant mollusk shells (Fig. 2; Table 1). This clayey sand forms the bottom of a locally shelly, fine to coarse sand unit containing numerous burrow systems referable to the ichnogenus *Ophiomorpha.*

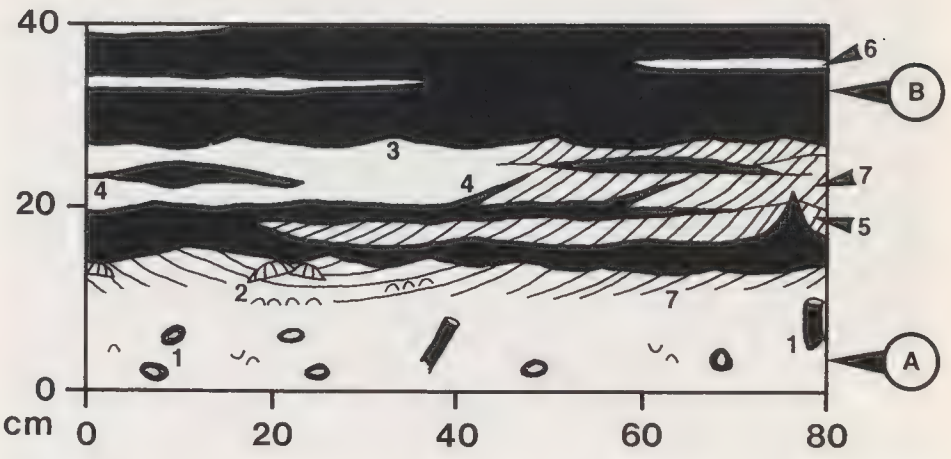

Fig. 8. Detailed sketch of intertongued contact between barrier bar sand (A) and overlying deltaic mud (B), as exposed in northeast wall of pit. 1, *Ophiomorpha* burrows; 2, accumulations of mollusk shells, larger shells being mainly those of *Dinocardium robustum;* 3, wavy contact caused by rippled bedding surface; 4, mud drapes and lenses; 5, clay tongue or flame; 6, fine sand lens; 7, ripple cross-lamination.

(These frequently branching, mud-lined subhorizontal tubes are probably the resul of the burrow-building behavior of the decapod crustacean *Callianassa biformis* (Hertweck, 1972, Fig. 7; Howard and Dorjes, 1972, Fig. 8; Frey *et al.,* 1978; Howard and Frey, 1980).) Interbeds of peat and clay occur near the middle and bottom of the *Ophiomorpha*-bearing interval. The clean sand with burrows is separated from the underlying clayey sand by a shell pavement formed by current-oriented valves of *Mercenaria campechiensis* encrusted by oysters and bryozoans; the top of the sand lacks callianassid burrow systems and is trough cross-bedded and ripple cross-laminated (Fig. 8). Many of the fossil shells collected at the borrow pit were derived from this uppermost subunit of the New Orleans trend sand, where they occurred as concentrations in cross-bedded, shelly sand lenses.

Radiocarbon dates on peat, collected near the middle and bottom of the sand, of 11,090± 90 and 29,860± 430 years B.P., are clearly too old (Charles R. Kolb, person. comm., 1981). Most authors believe that the barrier bar deposits accumulated between 5,000 and 4,000 years ago (see Corbeille, 1962; Saucier, 1963; Otvos, 1978).

The barrier bar sand is a part of a subsurface sand body that has been variously labeled "New Orleans barrier island," "Pine Island beach trend," "Pine Island Barrier," and "New Orleans barrier trend" (Corbeille, 1962; Saucier, 1963; Frazier,

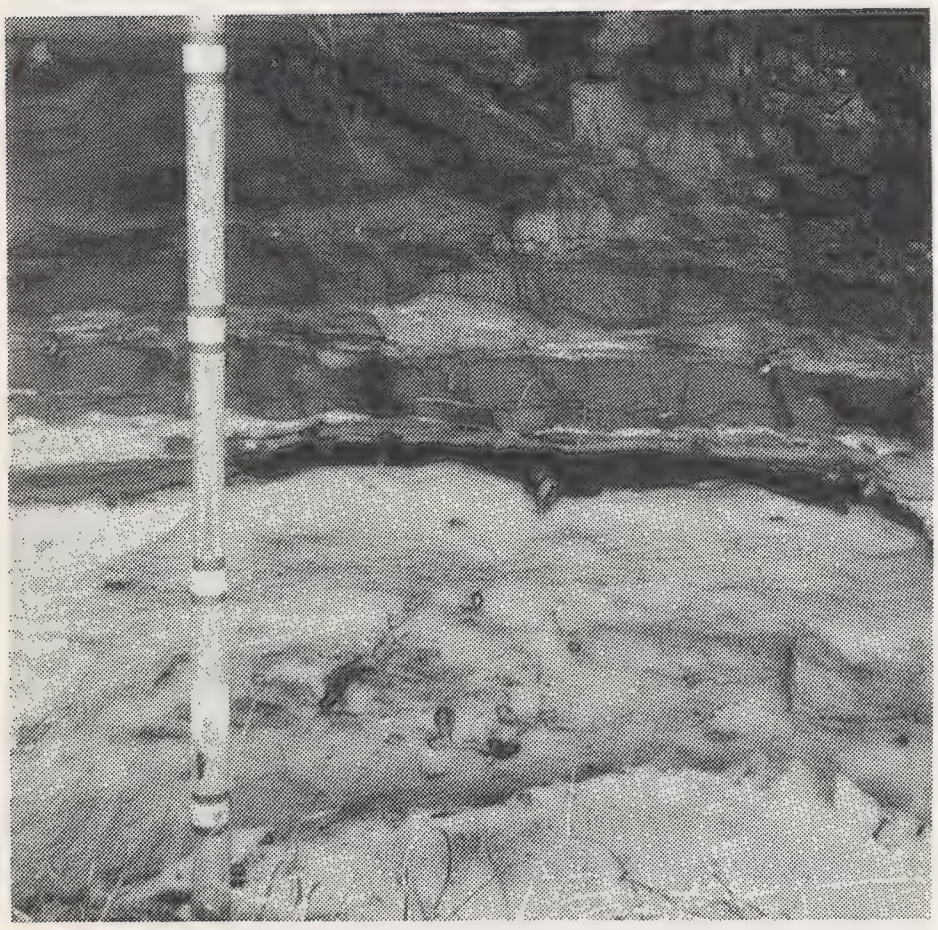

Fig. 9. Close-up view of contact between light-colored New Orleans barrier trend sand and superjacent, dark-colored St. Bernard Delta complex mud. Handle of digging tool is marked in 20 cm increments. (Not the same location as Fig. 8.)

1967; Otvos, 1978). At the Lake Carmel pit the sand has a rather constant thickness of 1.6 to 1.8 m, and at least locally must have a tabular shape. However, as revealed in subsurface borings, the overall geometry of the New Orleans barrier trend is actually a transversely notched, curvilinear prism (see Corbeille, 1962; Saucier, 1963). In outcrop, the light gray sand stands out in sharp contrast to the dark clays occurring above and below it (Fig. 9). The unit can be traced from near Pointe aux Herbes in eastern Orleans Parish, to Metairie in northeastern Jefferson Parish, through a distance of 30 km (Otvos, 1978; 1979).

Deltaic Mud

The uppermost unit exposed in the pit is a greenish-gray mud with silt and sand interlaminations (Fig. 2; Table 1). Although the upper half of the mud is overgrown and covered by weeds, a general coarsening upward pattern, involving addition of thicker and more numerous fine sand laminations, is apparent. The base of the mud is complexly interfingered with the ripple cross-laminated sand at the top of the barrier bar deposits (Fig. 8). The most typical sedimentary structures in exposed portions are continuous, parallel to wavy laminations; but sand lenses and beds are common near the contact, as are small vertical burrows filled with sand. Float derived from the upper part of the mud contains abundant *Rangia cuneata, Mytilopsis leucophaeata,* and *Littorina irrorata.* The unit is probably part of one of the older subdeltas of the St. Bernard delta complex (see Frazier, 1967, p. 301-306; Otvos, 1978, p. 342-345). Radiocarbon dates obtained by Otvos (1978) on deltaic deposits overlying barrier bar sand in a borrow pit on Morrison Road, about 5 km southwest of Lake Carmel, suggest an early St. Bernard subdelta buried the New Orleans barrier trend around 4,000 years ago in that area.

VI. SIGNIFICANCE OF RADIOCARBON DATES

Of the seven radiocarbon dates obtained from samples of peat and shell at the borrow pit, five dates appear to accurately reflect the age of the enclosing deposits. Stratigraphic positions of dated material are shown in Fig. 2, and Table 2 contains a list of the dates.

Sample A provided the oldest date (31,270± 370 years B.P.), and is the chief evidence that the youngest Pleistocene beds in the area are Wisconsin in age, rather than Sangamon as previously thought. If this single date is representative of the lowest unit exposed at the pit, then it seems likely that the youngest Pleistocene sediments beneath the New Orleans East area are possibly *not* time correlative with sediments occurring directly beneath the Prairie Terrace on the northern side of Lake Pontchartrain (Fig. 1, A). A later Pleistocene episode of deposition is indicated, and time-equivalence with sediments occurring beneath the Deweyville Terrace in Gulf Coastal Plain river valleys is a possibility. Clearly, more dates are needed to firmly establish the age and correlation of upper Pleistocene beds beneath New Orleans.

The radiocarbon date from the Little Woods paleosol (7,690± 70 years B.P.) is the minimum age for the soil, as discussed in the previous section. This is confirmed by radiocarbon dates from the peaty layer (7,290± 80 and 7,200± 50 years B.P.) at the base of the Holocene Michoud Formation located directly above the paleosol. The soil date probably reflects the latest series of root penetrations in the original soil, before

Table 2. Radiocarbon dates from the Lake Carmel borrow pit. All dates obtained and supplied by Dr. Charles R. Kolb, Institute for Environmental Studies, Louisiana State University.

SAMPLE	MATERIAL USED	DATE (years B.P.)	COMMENTS
A	Wood	31,270± 370	Oldest undisturbed organic material in section
B	Wood (root)	7,690± 70	Good estimate of minimum age of Little Woods paleosol
C	Peat rip-up clast	7,290± 80	Slightly disturbed, but *in situ* bedded peat; dates beginning of deposition in Pontchartrain Embayment in vicinity of borrow pit
D	Peat rip-up clast	7,200± 50	Slighty disturbed, but *in situ* bedded peat; dates beginning of deposition in Pontchartrain Embayment in vicinity of borrow pit
E	Bivalve shell	4,270± 50	*In situ* fossil; dates top of Michoud Fm. and estimates arrival of New Orleans trend barrier bar in area
F	Peat lens	11,090± 90	Woody material probably reworked from older deposits; date is out of place stratigraphically
G	Sandy peat	29,860± 430	Woody material probably reworked from older deposits; date is out of place stratigraphically

the solum layer was partially eroded and covered by marsh sediments.

Dates from the Michoud Formation are particularly interesting because they bracket the accumulation of sediments in that part of the Pontchartrain Embayment which once covered the Lake Carmel area. The estimate for the time span represented by the Michoud Formation at the pit, then, is about 3,000 years. If a uniform sedimentation rate is assumed, the Michoud accumulated at a rate of something like 1.33 mm/year, not taking into account effects of compaction. This points to a rather slow accumulation of fine-grained sediments in the Pontchartrain Embayment compared to other similar bay-sound environments (see Schindel, 1980).

Samples F and G from the New Orleans trend sand are obviously too old by factors of two and six, respectively. Dates in the range of 4,000 to 5,000 years were anticipated. There are three possible explanations for these anomalous dates from the same unit: 1) samples were misdated and laboratory technique is to blame; 2) samples have been contaminated since entombment with "dead" carbon and the surrounding sand has not acted as a closed system to isolate the dated material from natural contamination; or 3) Pleistocene woody material was reworked from headlands or perhaps brought downstream from old alluvial deposits, and was subsequently incorporated into the New Orleans barrier trend as a kind of beach drift deposit (see Howard and Frey, 1980, p. 88). The particulate, bedded nature of the peat, and the fact that the two anomalous dates are from the same ripple cross-laminated sand bed suggest transport and resedimentation of woody material originating in older Quaternary deposits.

I was unable to obtain dates from the St. Bernard deposits exposed in the pit.

VII. ENVIRONMENTAL HISTORY

The history of environmental changes in the vicinity of the Lake Carmel pit is typical of the Quaternary environmental history of the New Orleans area in being controlled by the interaction of four major geologic processes: 1) the construction of delta lobes associated with major river systems, such as the Mississippi and Pearl Rivers; 2) the

loading of the continental terrace with immense quantities of terrigenous clastics delivered to the coast by these major rivers, and subsidence of the southeastern Louisiana area along growth faults; 3) the abandonment of delta lobes, and the deposition of marine barrier bar and sound sediments in areas not being covered by prograding deltas; and 4) glacio-eustatic sea level fluctuations controlled by the expansion and recession of continental glaciers, and the resultant changes in the volume of the world ocean. The onshore stratigraphic framework that results from the interaction of such large-scale processes includes down-faulted sequences of intercalated deltaic and paralic/marine deposits, separated by unconformities and capped with soil zones (see cross-sections in Kolb *et al.*, 1975).

Pleistocene Environments

Because unaltered Pleistocene sediments at the base of the Lake Carmel section are not very well exposed, environmental interpretation must be somewhat tentative. However, the repeated interlaying of silt and sand, micaceous laminations, occasional wood fragments, and paleogeographic position basinward of the valleys of the Mississippi and Pearl Rivers suggest deposition in a delta front setting, probably as a distal distributary mouth bar (Elliot, 1978; Miall, 1979). These deposits are lithologically similar to delta front deposits occurring higher in the section within the St. Bernard Delta complex (Fig. 2, Table 1). Interestingly, like the St. Bernard deposits, the Pleistocene sediments cover a large sand body that could be an ancient barrier island or bar located beneath the south shore of Lake Pontchartrain (Fig. 1, B).

The Pleistocene deltaic sediments were deposited about 30,000 years ago when Gulf level was at or slightly lower than the present level. Shortly after this, Gulf level began to rapidly fall in response to the last series of Wisconsin glacial pulses, and the Deweyville deltaic environments in the New Orleans area were abandoned on the newly emergent coastal plain. The exposed surface of the Deweyville sediments underwent pedogenic alteration during the ensuing period of subaerial exposure, resulting in the formation of the Little Woods paleosol. This coastal plain soil evolved over a period beginning as early as 25,000 years B.P. and extending into the Holocene, to about 7,500 years B.P.

Older unconformity-bounded sequences occurring in the subsurface of the New Orleans area are similarly "punctuated" at their tops by buried soils, indicating long periods of exposure above sea level (Kolb and van Lopik, 1966; Kolb *et al.*, , 1975). The glacio-eustatic master control, then, seems to have superimposed a higher-order cyclic pattern on local Quaternary sequences, which are each composed internally of lower-order cyclic deltaic/marine units. Continued loading of the continental terrace in southeastern Louisiana has resulted in the vertical stacking of these cycles. Recognition of extensive paleosol units like the Little Woods and their associated major unconformities is crucial in identifying these higher-order cycles (Fig. 10). However, these important indicators of prolonged, widespread shelf emergence should not be confused with localized pedogenic features and hiatuses associated with delta plain and delta abandonment facies (*cf.* Elliot, 1978, p. 129).

Holocene Environments

As a result of downwarping and subsidence along faults in the area, the environs of New Orleans and southern Lake Pontchartrain were probably topographically lower than adjacent segments of the Gulf Coastal Plain in southwestern Louisiana and southern Mississippi when the Holocene transgression began. This low-lying coastal depression was flooded while the surrounding coastal plain remained emergent (Saucier, 1963, Figs. 5, 13, 15); the bay-sound environment that formed in the depression is known as the Pontchartrain Embayment. The embayment existed from about 7,500 to 3,000 years B.P., until first barrier bars and later St. Bernard Delta lobes isolated this coastal compartment and restricted communication with the Gulf (Otvos, 1978, Fig. 16). The relict geomorphic feature corresponding to the embayment is Lake Pontchartrain, and the lithostratigraphic evidence that remains of this bay-sound environment is the Michoud Formation. The history of the south-central portion of the Pontchartrain Embayment is preserved in the Lake Carmel section.

About 7,300 years B.P. Gulf waters reached the Lake Carmel area, as demonstrated by the radiocarbon dates on peat rip-up clasts found at the base of the Michoud. The clasts were formed from originally continuous peat layers that were deposited in a fresh to brackish marsh environment. As the coastal marshes in the Lake Carmel area were submerged, the peat was reworked by currents and waves to form flat, rotated fragments that eventually became embedded in the overlying blanket of bay-sound mud. As the transgression proceeded, water depth within the embayment probably increased to several meters, although the low diversity of mollusks contained within the bay-sound mud suggests that salinity remained rather low until the sand of the New Orleans trend began to accumulate in the area (see Appendix). Estuarine taxa occur in limited numbers throughout the Michoud at the borrow pit, with open-bay species only becoming slightly more abundant toward the top of the unit. Boring clams are numerous near the top of the Michoud indicating that clay firm-grounds were common in the vicinity of the borrow pit.

One of the most interesting features of the bay-sound deposits is the two sand interbeds located near the middle of the unit (Fig. 2). The beds are composed of well-sorted, fine-grained quartz sand, can be traced throughout the borrow pit, and have load structures formed on their lower contacts with the bay-sound clay (Fig. 7). These characteristics would seem to indicate that the sand interbeds were transported into the Pontchartrain Embayment and deposited, perhaps as tempestites, on a soft clay substratum. Internally, the sand interbeds have been more or less homogenized as a result of bioturbation. Sand clasts and flat sand lenses occurring in the surrounding mud may have had similar origins, with clasts representing the obliteration of originally continuous sand layers by burrowing organisms and lenses indicating reworking of sand layers by currents into minor sand-starved ripples that migrated over a muddy sound floor. The sand may have been derived by storm erosion of a sand bar lying seaward of the embayment, by storm transport from the incipient New Orleans trend some distance to the northeast, or perhaps through erosion of a nearby Pleistocene

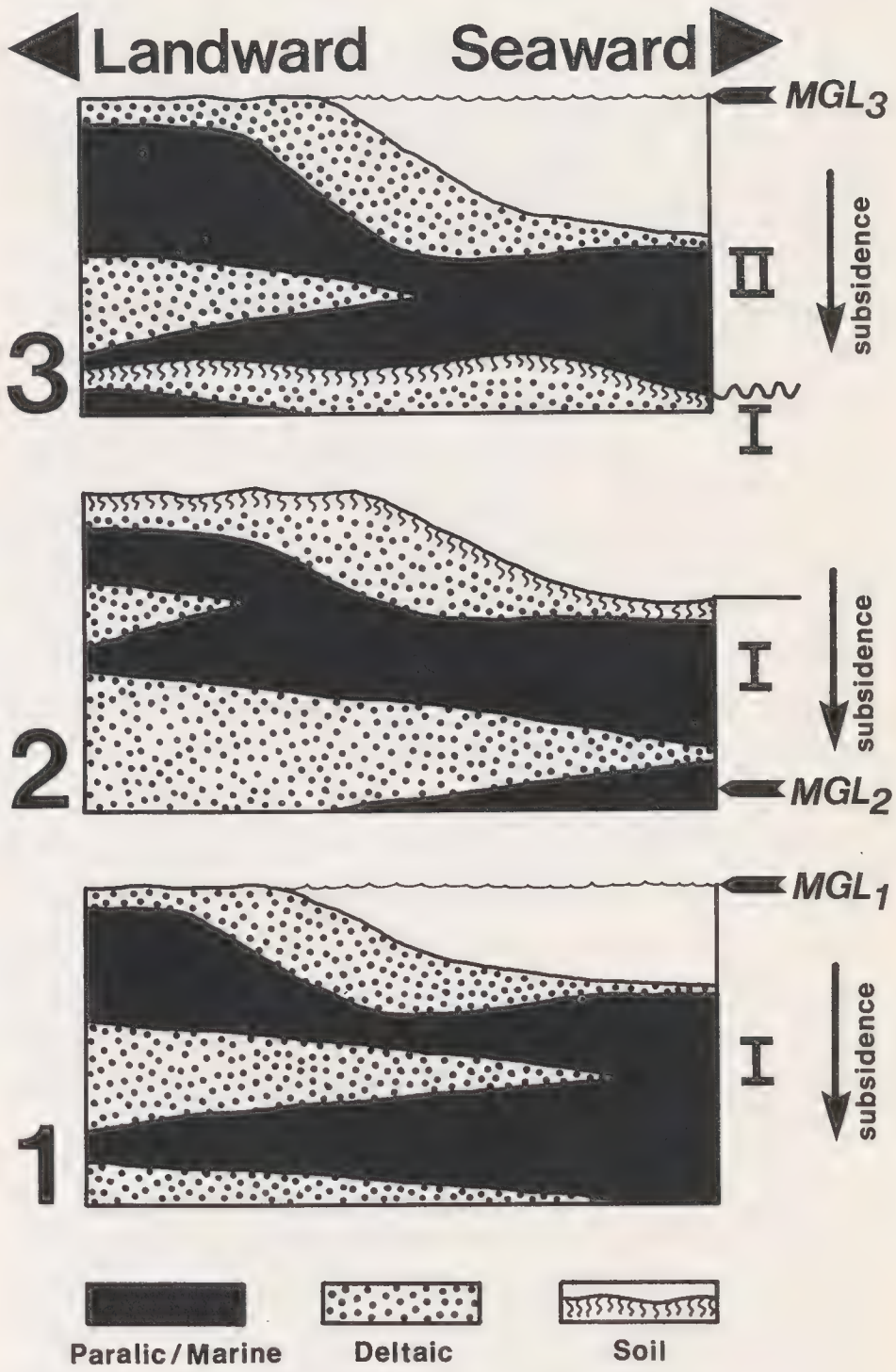

Fig. 10. Stacking of unconformity-bounded coastal sequences of deltaic and paralic/marine deposits in the shallow subsurface Pleistocene of southeastern Louisiana. 1, Deltaic, paralic, and marine sediments interlayered during high stand of mean Gulf level (MGL_1) as the result of shift in locations of delta lobes and associated coastal environments. 2, Lowering of gulf level (MGL_2) during full glaciation exposes large areas of continental shelf and extensive soil development ensues. 3, Cycle is repeated beginning with a rise in gulf level (MGL_3), resubmergence of the continental shelf, and deposition of sediments in sequence II. Subsidence is more or less continuous throughout. Intercalation of deltaic with paralic/marine deposits, resulting mainly from changes in locations of delta lobes, sounds, and open shelf areas, gives rise to cyclothem-like units; stacking of unconformity-bounded sequences gives rise to mesothem-like units (see Hallam, 1981, p. 129-132). Higher-order cyclic sequences are separated by major unconformities marked by extensive, well-developed paleosols. (Not drawn to scale.)

headland somewhere in the vicinity of Slidell.

The discontinuous layer of muddy sand located directly above the Michoud Formation (Fig. 2) contains the highest diversity and numbers of untransported mollusks at the borrow pit. The overlying cleaner sand contains many more taxa, but most have been transported from marine environments (see Appendix). The muddy sand probably represents a subtidal Gulf floor environment; whereas the large-ripple cross-laminated sand above it, containing clay drapes in ripple troughs, thin peat interbeds and abundant *Ophiomorpha* tubes of the type produced by callianassid decapods in protected settings, accumulated in bar trough and lower bar flank environments. The top of the New Orleans trend deposits at Lake Carmel is a ripple cross-laminated fine to coarse sand with trough cross-laminated shelly lenses, indicating very shallow subtidal to intertidal bar crest and upper bar flank environments. It does not appear that the New Orleans trend was an emergent sand ridge in this part of Orleans Parish, except perhaps during very low tides. The sand probably began accumulating at the Lake Carmel borrow pit after about 4,300 years B.P., as suggested by the radiocarbon date from the top of the Michoud (Table 2; *cf.* Otvos, 1978, Fig. 16).

Complete isolation of the Pontchartrain Embayment occurred when early St. Bernard delta sublobes encroached upon and buried the New Orleans trend in eastern Orleans Parish. Otvos (1978) believes that the process of deltaic encroachment began around 3,800-4,000 years B.P. and that isolation was completed about 2,800 years B.P. At Lake Carmel the top of the barrier trend sand interfingers with dark-colored mud with parallel and wavy-horizontal silt and sand interlaminations. The mud unit seems to be the basal layer of one of the older St. Bernard lobes, and displays an overall coarsening upward owing to incorporation of thicker and more numerous sand interlaminations. This suggests that the New Orleans trend sand was first blanketed by prodeltaic mud and later by coarser delta front deposits. Thickness of St. Bernard deltaic deposits at the borrow pit is 4.5 m; to the south of Lake Carmel, where three or four lobes are stacked in vertical succession, total thickness of deltaic deposits exceeds 14 m. The deltaic blanket exposed at the borrow pit is perhaps part of the Bayou Terre aux Boeufs lobe described by Frazier (1967), but unfortunately geochronometric control at Lake Carmel is lacking.

VIII. FUTURE WORK

The exposures of sediments and fossils at the Lake Carmel borrow pit presented the rare opportunity to collect detailed stratigraphic information relating to the development of the southern portion of the Pontchartrain Embayment, the sedimentary environments of the New Orleans trend, and to the entombment of the barrier trend by St. Bernard deltaic deposits. The unconformity between Pleistocene and Holocene deposits, and the age and nature of the subjacent Pleistocene beds also could be studied at the pit allowing for the first time a close look at the contact separating two Quaternary depositional sequences in southeastern Louisiana.

However, many questions remain to be answered. Future investigations might profitably focus upon the following "loose ends" of local Quaternary stratigraphy:

1) What role has faulting played in shaping the paleogeography of the Mississippi Delta region and controlling the positions of basins and depositional landforms?

2) Are the Pleistocene unconformity-bounded sequences beneath the New Orleans area composed of paralic and deltaic units similar to the Holocene sequence, and what are the ages of these essentially unstudied Pleistocene deposits?

3) What are the coastwise equivalents of the Pleistocene units in the subsurface of Orleans Parish? Are the units mapped and described by Otvos in southern Mississippi recognizable in downfaulted sequences beneath southern Lake Pontchartrain and New Orleans?

4) What do the downfaulted sequences of intercalated deltaic and paralic/marine deposits capped by paleosols of regional extent tell us about the origin of large terrigenous clastic wedges in nearshore settings affected by eustatic changes in sea level? Are the pre-Quaternary deltaic deposits in the northern Gulf Coastal Plain, like the economically important Fleming Group, composed of similar sequences?

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X. APPENDIX

MOLLUSKS FROM THE LAKE CARMEL BORROW PIT

All taxa collected and identified by Mr. George Mollyn. (Symbols representing relative abundance estimates have the following meanings: 5 = abundant, 4 = common, 3 = moderately common, 2 = uncommon, 1 = rare, ? = from float material. Sample intervals refer to Fig. 2.)

TAXA	Lower Bay-Sound Clay (9.0 to 10 m)	Middle Bay-Sound Clay (7.5 to 9.0 m)	Upper Bay-Sound Clay (6.3 to 7.5 m)	Base of Barrier Bar (6.0 to 6.3 m)	Barrier Bar Sand (4.5 to 6.0 m)
GASTROPODA					
Fissurellidae					
Diodora cayenensis (Lamarck)					1
Neritidae					
Neritina reclivata (Say)					3
N. virginea (Linné)					1
Littorinidae					
Littorina irrorata (Say)	1				1
Vitrinellidae					
Cyclostremiscus suppressus (Dall)					1
C. pentagonus (Gabb)					2
Teinostoma biscaynense Pilsbry & McGinty					2
Solariorbis infracarinata Gabb					2
S. mooreana Vanatta					1
Caecidae					
Caecum imbricatum Carpenter					1
C. johnsoni Winkley					1
Cerithidae					
Diastoma varium (Pfeiffer)					5
Seila adamsi (H. C. Lea)					1
Litiopa melanostoma Rang					1
Triphoridae					
Triphora perversa nigrocincta (C. B. Adams)					1
Epitoniidae					
Epitonium angulatum (Say)				1	1
E. rupicola (Kurtz)					1?
Epitonium cf. *E. tollini* Bartsch					1
Epitonium cf. *E. multistriatum* (Say)					1

TAXA	Lower Bay-Sound Clay (9.0 to 10 m)	Middle Bay-Sound Clay (7.5 to 9.0 m)	Upper Bay-Sound Clay (6.3 to 7.5 m)	Base of Barrier Bar (6.0 to 6.3 m)	Barrier Bar Sand (4.5 to 6.0 m)
Eulimidae					
Eulima cf. *E. bilineatus* (Alder)					1
Balcis cf. *B. arcuata* (C. B. Adams)					1
Balcis cf. *B. jamaicensis* (C. B. Adams)				1	
Balcis cf. *B. gracilis* (C. B. Adams)					1
Strombidae					
Strombus alatus Gmelin					3
Calyptraeidae					
Crepidula fornicata (Linné)				3	3
C. plana Say					3
Naticidae					
Neverita duplicatus (Say)	2	1	1	2	3
Sinum perspectivum (Say)					3
Tectonatica pusilla (Say)					3
Cassididae					
Phalium granulatum (Born)					3
Cymatiidae					
Distorsio clathrata (Lamarck)					1?
Tonnidae					
Tonna galea (Linné)					1?
Ficidae					
Ficus communis Röding					1?
Muricidae					
Hexaplex fulvescens (G. B. Sowerby, I)					1?
Thais haemastoma floridana (Conrad)					2
T. h. canaliculata (Gray)					1
Columbellidae					
Anachis obesa (C. B. Adams)					4
A. semiplicata (Stearns)	1				1
Mitrella lunata (Say)					3
Buccinidae					
Cantharus cancellarius (Conrad)				3	3
Melongenidae					
Melongena corona (Gmelin)					1?
Busycon perversum pulleyi Hollister					2
B. spiratum plagosum (Conrad)					2
Nassariidae					
Nassarius vibex (Say)	4		1	5	3
N. acutus (Say)	2	1	3	3	4
Fasciolariidae					
Fasciolaria lilium hunteria (Perry)					1?
Olividae					
Oliva sayana Ravenel				1	2
Olivella mutica (Say)					4
Volutidae					
Scaphella junonia (Lamarck)					1?
Cancellaridae					
Cancellaria reticulata (Linné)					1
Marginellidae					
Marginella apicina Menke				1	1

TAXA	Lower Bay-Sound Clay (9.0 to 10 m)	Middle Bay-Sound Clay (7.5 to 9.0 m)	Upper Bay-Sound Clay (6.3 to 7.5 m)	Base of Barrier Bar (6.0 to 6.3 m)	Barrier Bar Sand (4.5 to 6.0 m)
Terebridae					
Terebra dislocata (Say)					2
T. concava Say					1
Hastula salleana (Deshayes)			1?		1
Turridae					
Kurtziella atrostyla (Tryon)					2
K. serga (Dall)					1
Nannodiella oxia (Bush)					1
Acteonidae					
Acteon punctostriatus (C. B. Adams)					1
Acteocinidae					
Acteocina canaliculata (Say)	1	1		1	3
Atyidae					
Volvulella persimilis (Mörch)					1
Pyramidellidae					
Pyramidella crenulata (Holmes)					2
Odostomia impressa (Say)					2
O. seminuda (C. B. Adams)					1
Odostomia cf. *O. gibbosa* Bush					1
Odostomia cf. *O. livida* Rehder					1
Turbonilla interrupta (Totten)	1		2		1
Peristichia agria Dall					1
Eulimastoma cf. *E. weberi* (Morrison)					3
Eulimastoma cf. *E. teres* (Bush)					2
Ellobiidae					
Melampus bidentatus (Say)					1
Cuvieridae					
Creseis acicula (Rang)					1
BIVALVIA					
Nuculanidae					
Nuculana concentrica (Say)	1	1	2	1	2
N. acuta (Conrad)					1
Arcidae					
Anadara transversa (Say)					5
A. ovalis (Bruguière)	1	1	1	2	4
A. brasiliana (Lamarck)					4
Noetia ponderosa (Say)					3
Mytilidae					
Geukensia demissa granosissima (G. B. Sowerby, III)	1				1
Brachidontes exustus (Linné)	1				1
Pinnidae					
Atrina serrata (G. B. Sowerby, I)		1			1
Pectinidae					
Argopecten irradians concentricus (Say)					2
A. gibbus (Linné)					1
Plicatulidae					
Plicatula gibbosa Lamarck					1
Anomiidae					
Anomia simplex d'Orbigny					3

TAXA	Lower Bay-Sound Clay (9.0 to 10 m)	Middle Bay-Sound Clay (7.5 to 9.0 m)	Upper Bay-Sound Clay (6.3 to 7.5 m)	Base of Barrier Bar (6.0 to 6.3 m)	Barrier Bar Sand (4.5 to 6.0 m)
Ostreidae					
Crassostrea virginica (Gmelin)	2			2	5
Lucinidae					
Linga amiantus (Dall)					5
Parvilucina multilineata (Tuomey & Holmes)					4
Pseudomiltha floridana (Conrad)					2
Anodontia alba Link					1?
Ungulinidae					
Diplodonta semiaspera (Philippi)					2
Diplodonta cf. *D. soror* C. B. Adams			4	3	
Chamidae					
Arcinella cornuta Conrad					1
Chama congregata Conrad					1?
Lasaeidae					
Aligena texasiana Harry					1?
Leptonidae					
Lepton lepidum Say					1
Nearomya floridana (Dall)					1?
Crassatellidae					
Crassinella lunulata (Conrad)					5
Cardiidae					
Trachycardium muricatum (Linné)					2
T. isocardia (Linné)					1?
Laevicardium laevigatum (Linné)					2
Dinocardium robustum (Lightfoot)				2	4
Mactridae					
Mactra fragilis Gmelin					1
Spisula solidissima similis (Say)					3
Mulinia lateralis (Say)		1	3	4	5
Rangia cuneata (Gray)	1				2
R. flexuosa (Conrad)					2
Raeta plicatella (Lamarck)			2	2	3
Mesodesmatidae					
Ervilia cf. *E. concentrica* (Holmes)					1?
Solenidae					
Ensis minor Dall			1		3
Tellinidae					
Tellina aequistriata (Say)					2
T. alternata Say			2	4	2
T. texana Dall	1		2	2	2
T. iris Say					1
Tellidora cristata (Récluz)				2	2
Strigilla mirabilis (Philippi)					4
Macoma constricta (Bruguière)			1		4
M. tenta (Say)	1		2	3	
Donacidae					
Donax texasianus Philippi				2	5
D. variabilis roemeri Philippi					2

TAXA	Lower Bay-Sound Clay (9.0 to 10 m)	Middle Bay-Sound Clay (7.5 to 9.0 m)	Upper Bay-Sound Clay (6.3 to 7.5 m)	Base of Barrier Bar (6.0 to 6.3 m)	Barrier Bar Sand (4.5 to 6.0 m)
Semelidae					
Semele proficua (Pulteney)					2
S. bellastriata (Conrad)					1
Abra aequalis (Say)			2	3	5
Solecurtidae					
Tagelus plebeius (Lightfoot)					4
T. divisus (Spengler)			1	2	2
Dreissenidae					
Mytilopsis leucophaeata (Conrad)					1
Veneridae					
Agriopoma texasiana (Dall)	2	1	1	1	
Macrocallista nimbosa (Lightfoot)					1
Dosinia discus (Reeve)			2	4	3
Cyclinella tenuis (Récluz)			1?		
Gemma gemma Totten					2
Chione cancellata (Linné)					4
C. intapurpurea (Conrad)					2
Timoclea grus (Holmes)					1
Mercenaria campechiensis (Gmelin)	2			5	3
Anomalocardia auberiana (d'Orbigny)					1
Petricolidae					
Petricola pholadiformis (Lamarck)			4		2
Myidae					
Paramya subovata (Conrad)			1		1
Corbulidae					
Corbula contracta Say	5	1			3
C. swiftiana C. B. Adams					5
Pholadidae					
Barnea truncata (Say)			3	1	
Cyrtopleura costata (Linné)	1		3	2	1
Diplothyra smithii Tlryon				2	
Pandoridae					
Pandora trilineata Say					1
Periplomatidae					
Periploma margaritaceum (Lamarck)				1	2
SCAPHOPODA					
Dentaliidae					
Dentalium texasianum Philippi					2
Dentalium sp.					1

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BIOGENIC SHELL DAMAGE IN THE SMALL GASTROPOD *ODOSTOMIA IMPRESSA* (SAY)

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I. ABSTRACT

Nearly every shell and fragment of the small pyramidellid snail *Odostomia impressa*,* occurring in very large numbers in and around modern intertidal oyster banks in coastal Georgia, shows evidence of biogenic shell damage. Almost all of the shells have repaired or unrepaired fractures caused by crabs; most of the shell fragments also appear to be the result of attack by crabs, rather than physical breakage by waves or compaction. Most of the specimens are infested by an algal microborer, which gives shells a chalky, excoriated appearance. Gastropod borings in the Georgia odostomes were very rare. In a comparison with *O. impressa* shells from subtidal oyster banks in Virginia, it was found that crab damage in the Georgia sam-

*The generic label *Odostomia* will be used in this paper, although it should be pointed out that Robertson (1978) has recently proposed that American odostomes be separated into two genera: *Boonea* Robertson, 1978 (which includes *Odostomia impressa)*, and *Fargoa* Bartsch, 1955. For the present, I prefer to retain the traditional name *Odostomia* for three reasons: 1) for the sake of simplicity, as the present study is not a taxonomic treatment; 2) because the revision begun by Robertson, although it represents a step in the direction of a more realistic suprageneric grouping of the odostomes, is preliminary and not exhaustive; and 3) because paleontologists like myself cannot employ the sexual anatomical criteria used to allocate species to *Boonea* or *Fargoa*.

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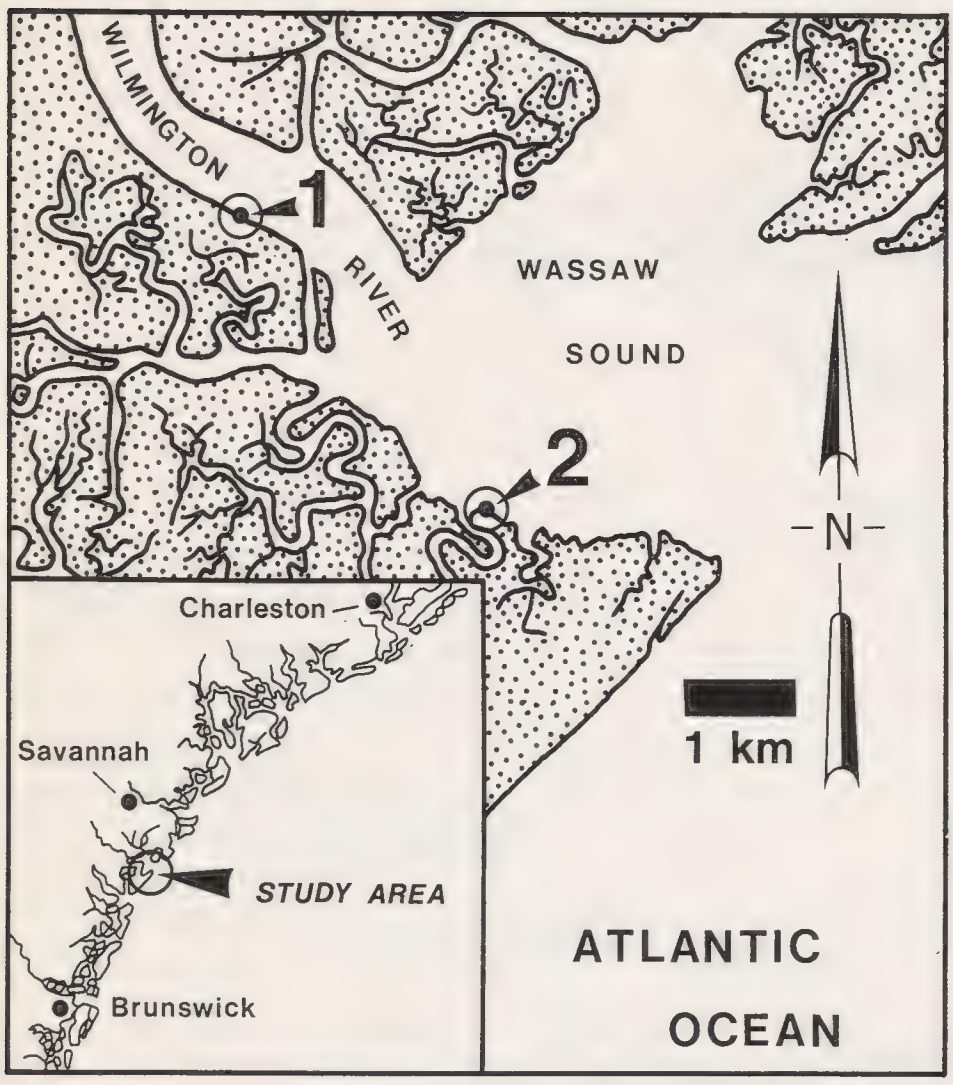

Figure 1. Map showing general location of the study area (inset) and the lower Wilmington River-Wassaw Sound estuary. Locality 1, just upstream from Sister Island; samples H-1 through H-4. Locality 2, near mouth of Blue Bank Creek; samples W-1 through W-5 (see Table 2). (Based on N.O.A.A. Savannah River and Wassaw Sound Map, 1980.)

ples was much more extensive, but that many of the Virginia shells had been bored by the bryozoan *Electra*.

A conservative estimate of the average frequency of fatal attacks on Georgia odostomes from intertidal oyster banks is about 25 percent, using samples from time-averaged shelly deposits. The predator on *O. impressa* in this setting is probably the xanthid crab *Panopeus herbstii*, which is in turn preyed upon by raccoons, birds, and fish. The algal microborer responsible for microscopic holes and striations in odostome shells appears to be a cyanophyte typical of lower intertidal zones.

II. INTRODUCTION

Over the past two decades a large literature has accumulated on the varieties and ecologic significance of biogenic shell damage in fossil mollusks. This type of shell damage is caused largely by predatory attacks (*e.g.*, snail borings in bivalve shells, crab damage inflicted upon snail shells), by endolithic organisms exploiting mollusk shells as habitats (*e.g.*, boring algae and fungi in various types of mollusk shells, polydorid worm borings in bivalve shells), and by shell-growth adjustments to infestation by parasites (*e.g.*, pyramidellid infestation of oysters). Skeletal overgrowths by epilithic organisms represent a special category of biogenic shell damage affecting both living and abandoned mollusk shells. (Good summaries of the literature dealing with the interpretation of shell damage are found in the following sources: Reyment, 1971; Bishop, 1975; Golubic *et al.*, 1975; Vermeij, 1978; Boucot, 1981; Dodd and Stanton, 1981.)

Nearly all of the studies of shell damage inflicted by the activities of predatory organisms on mollusks focus on large prey species. With the exception of a study of the frequency of crab predation on minute cerithiacean gastropods by Dudley (1980), I know of no studies that make use of small mollusks. The purpose of the present study is to describe the varieties and significance of shell damage in a diminutive pyramidellid snail, *Odostomia impressa* (Say, 1821), from intertidal oyster banks in the Wassaw Sound area of coastal Georgia. *Odostomia impressa* was used because of its abundance in modern shell deposits along the margin of the sound, and because nearly every specimen examined showed some form of biogenic shell damage.

During a survey of the environmental distribution of pyramidellid snails from Wassaw Sound (Miller, in press), it was discovered that the most common and easily detected form of damage evidenced by *O. impressa* had been inflicted by predatory crabs; many of the shells had been infested by algal microborers, and a few had been attacked by boring gastropods. Because all of these forms of shell damage caused by predators (or potential predators) and endolithic associates leave a more or less indelible trace in the carbonate substrate of *O. impressa* shells, all are potentially preservable as trace fossils. Moreover, the traces of predation on *O. impressa* give an indication of the position of this abundant and widely distributed gastropod in the trophic structure of intertidal oyster bank communities.

TABLE 1. Sample station data. The location of the two oyster banks sampled is shown in Fig. 1.

SAMPLE NUMBER	ENVIRONMENTAL SETTING	SAMPLE VOLUME
WASSAW SOUND		
W-1	high intertidal rubble flat behind oyster bank	1.00 liter
W-2	low intertidal slope in front of oyster bank	1.00
W-3	shallow tidal slough near oyster bank	1.00
W-4	high intertidal sediment pond within oyster bank	1.00
W-5	high intertidal sediment pond within oyster bank	0.75
WILMINGTON RIVER		
H-1	shelly bar in tidal creek near oyster bank	1.00
H-2	middle intertidal oyster bank (dead)	0.75
H-3	low intertidal rubble slope in front of oyster bank	0.75
H-4	high intertidal shell-armored levee	1.00

III. METHODS

Nine bulk samples of shelly sediments were collected from two oyster banks located along the edge of the lower Wilmington River and Wassaw Sound (Fig. 1). A variety of intertidal to very shallow subtidal environments was sampled representing a cross-section of estuarine margin settings (Table 1). Samples were wet-sieved on a screen having 1 mm openings, dried, and picked for specimens of *Odostomia impressa*. All shells and fragments were carefully examined using a dissecting microscope for signs of predation and endolithic infestation, and selected typical specimens were examined using a scanning electron microscope. An inventory of the condition of shells is shown in Table 2.

In addition, two samples collected from subtidal "oyster rocks" in the lower James River, Virginia, by Mr. James P. Whitcomb, were used in comparisons with the intertidal material from Georgia. These samples were collected from Brown Shoal (V-1) and Wreck Shoal Rock (V-2) by dredging 30 and 22 liters, respectively, of oyster shells and sediments. The 1 to 5 mm sediment fraction was dried and picked for *O. impressa;* all specimens were examined for shell damage using a dissecting microscope.

TABLE 2. Condition of *Odostomia impressa* shells from Wilmington River and Wassaw Sound oyster banks. Sample numbers are keyed to Table 1; percentages are given in parentheses. An asterisk indicates a percentage used in a statistical test for significant difference between W-1 and H-3, the largest samples from Georgia (see text).

SAMPLE NUMBER	Whole Shells	Apical Fragments	Decollate Shells	Apertural Fragments	Whorl Shards	TOTAL SPECIMENS
W-1	234 (32.4)	171 (23.7)*	74 (10.2)	172 (23.8)	71 (9.8)	722
W-2	0	0	0	1 (50.0)	1 (50.0)	2
W-3	5 (83.3)	0	1 (16.7)	0	0	6
W-4	37 (46.3)	15 (18.8)	0	24 (30.0)	4 (5.0)	80
W-5	166 (30.0)	129 (23.3)	35 (6.3)	124 (22.4)	99 (17.9)	553
H-1	6 (27.3)	7 (31.8)	2 (9.1)	7 (31.8)	0	22
H-2	9 (69.2)	4 (30.8)	0	0	0	13
H-3	73 (33.6)	59 (27.2)*	18 (8.3)	60 (27.6)	7 (3.2)	217
H-4	53 (57.6)	24 (26.1)	5 (5.4)	9 (9.8)	1 (1.1)	92

IV. VARIETIES OF BIOGENIC DAMAGE

Crab-Inflicted Damage. — Shells damaged by crab predation occur in three forms: 1) whole shells with minor apertural damage, caused by an unsuccessful attack (Pl. 1, fig. 1); 2) various kinds of shell fragments, suggesting in some cases the death of the prey (Pl. 1, figs. 2, 3, 4, and 5); and 3) shell damage that was repaired by the would-be victim (Pl. 1, fig. 6; Fig. 2). Almost every specimen of *Odostomia impressa* from the Wassaw Sound area showed signs of breakage or peeling caused by crabs; crab damage was far less ubiquitous in the Virginia samples (Table 3).

Many of the whole shells had chipped outer lips on the body whorl. Shell breaks resulting from apertural chipping, or desquamation, are usually arcuate in outline and do not extend back along the body whorl more than one-half volution (Pl. 1, fig. 1). The edges of the breaks are normally sharp and fresh in appearance. There was no statistically significant difference in the proportion of shells with unrepaired apertural damage between the lower Wilmington River and Wassaw Sound sample localities, considering only the largest samples ($z = 1.297$, $\alpha = 0.05$).

Crabs peel the odostomes by holding the spire with one cheliped and chip away fragments of the outer lip with the other (Bishop, 1975, Fig. 12.2), the by-products of which are the numerous whorl shards found in some samples (Pl. 1, fig. 2; Table 2). Chipped apertures represent unsuccessful predation attempts that have been repaired in some specimens by new shell growth (Pl. 1, fig. 6). Repaired peeling is distinguished from other cracks and shell blemishes by the following charactertistics: 1) newly formed shell appears imbricated beneath older shell below the repaired fracture; 2) the spiral cords forming the surface ornamentation of *O. impressa* are offset slightly at fracture lines; and 3) the arcuate outline of the fracture line separating the pre-attack from the post-attack portions of the shell (Schindel *et al.*, 1982). Fig. 2 shows a close-up view of a repaired fracture.

Other specimens are indicative, at least in part, of fatal attacks on the odsotomes by crabs. These include decollate shells with the apical and apertural areas broken off, probably by the scissor-like pinching action of chelipeds (Pl. 1, fig. 3); apertural fragments (Pl. 1, fig. 5); and apical fragments (Pl. 1, fig. 4). It is not known if all decollate shells should be regarded as evidence of fatal attacks, and some individuals loosing apertural fragments in attacks may have been able to repair the damage. However, an unrepaired apical fragment, wherein the

TABLE 3. Predation traces on *Odostomia impressa* shells. Only whole shells are considered; percentages are given in parentheses. An asterisk indicates a percentage used in a statistical test for significant difference between W-1 and H-3 (see text).

SAMPLE NUMBER	Completed Gastropod Borings	Damage Inflicted by Crabs					TOTAL WHOLE SHELLS EXAMINED
		Unrepaired Apertural Damage	Shell Repair Frequency				
			1	2	3	4	
W-1	11 (4.7)	218 (93.2)*	103 (44.0)*	21 (9.0)	5 (2.1)	1 (0.4)	234
W-3	0	2 (40.0)	2 (40.0)	1 (20.0)	—	—	5
W-4	0	27 (73.0)	18 (48.6)	4 (10.8)	—	—	37
W-5	7 (4.2)	159 (95.8)*	58 (34.9)	7 (4.2)	3 (1.8)	—	166
H-1	0	6 (100.0)	2 (33.3)	—	—	—	6
H-2	0	9 (100.0)	2 (22.2)	—	—	—	9
H-3	3 (4.1)	71 (97.3)*	29 (39.7)*	1 (1.4)	—	—	73
H-4	2 (3.8)	51 (96.2)	14 (26.4)	8 (15.1)	—	—	53
V-1	0	4 (25.0)	3 (18.8)	—	—	—	16
V-2	0	16 (22.2)	11 (15.3)	1 (1.4)	—	—	72
						Grand Total =	671

shell has been peeled back into the penultimate whorl or even farther up the spire, is taken as a strong indication that the predator was successful in attacking and extracting enough of the soft parts to cause the death of the snail. A count of apical fragments in a sample from a time-averaged shell accumulation, then, can be regarded as an average minimum estimate of the frequency of successful attacks by predatory crabs. In the Georgia samples (Table 2), it appears that the average frequency of successful attacks was around 25 percent, with no statistically significant difference between the lower Wilmington River and Wassaw Sound localities (comparing proportion of apical fragments in the largest samples; $z = 0.513$, $\alpha = 0.05$).

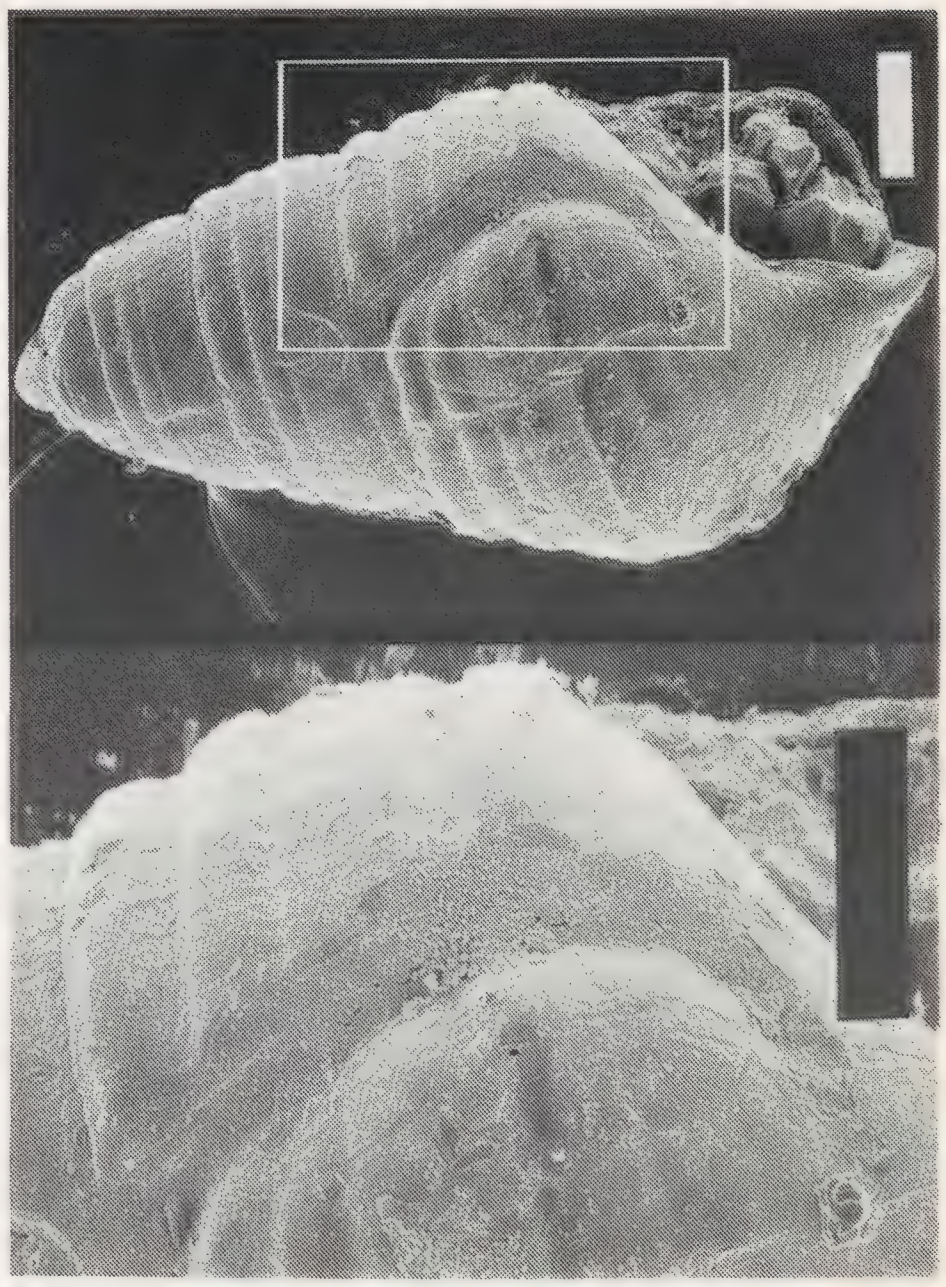

Figure 2. Repaired shell fracture in immature *Odostomia impressa*. Notice offset spiral cords and imbrication of younger portion of shell beneath older portion at the break. (Both bar scales represent 200 μm.)

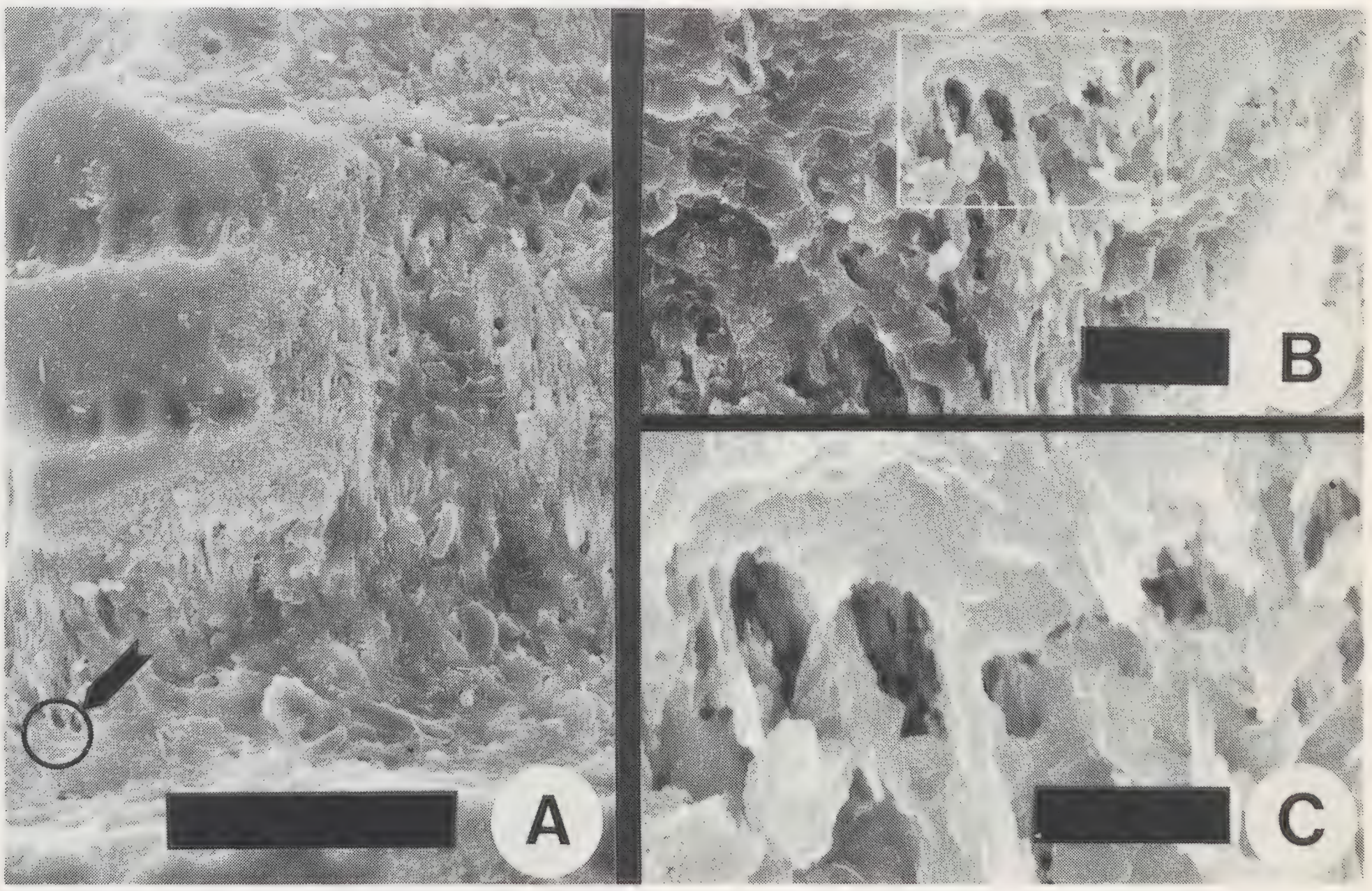

Figure 3. A, Excoriated shell surface surrounding an island of undamaged surface. Arrow indicates area shown in B. (Bar scale represents 100 μm.) B, Close-up view of microborings typical of excoriated surfaces. (Bar scale represents 20 μm.) C, Area shown in B under higher magnification. Notice that borings enter shell surface at oblique angle, and the smaller microborings in lower left-hand corner. (Bar scale represents 10 μm.)

Interestingly, the samples from subtidal oyster banks in the James River, Virginia, contained only slightly damaged or repaired whole shells, with no specimens indicative of fatal attacks. Caution must be taken in interpreting this comparison because of different methods of collecting specimens (bulk sediment samples in Georgia *vs.* dredge samples in Virginia) and because the Georgia samples come from time-averaged shelly deposits containing several generations of odostomes, whereas the Virginia shells contained the retracted soft parts of snails and seem to represent cohorts of living populations. Crab predation on *O. impressa* appears to be an important cause of mortality in intertidal settings, at any rate, and is unreported in the literature.

Finally, some of the individuals of *O. impressa* with repaired fractures appear to have been attacked several times (Table 3). It is not known if each fracture repair is indicative of a separate unsuccessful attack or if the fractures are repaired multiple shell injuries in some cases inflicted during the same attack, with the fractures located high on the spire indicating accessory damage rather than previous episodes of attempted predation. Although there was no statistically significant difference in the proportion of shells with at least one repair between the lower Wilmington River and Wassaw Sound localities (considering only largest samples; $z = 0.648$, $\alpha = 0.05$), the shells from the sound margin oyster bank did exhibit more examples of multiple repairs. The highest number of multiple repairs observed was four (Table 3).

Algal Microborers. — The second most frequent form of shell damage in the Georgia samples was excoriation, mainly of apical areas, by endolithic or semi-endolithic microborers (Fig. 3, A). At low magnification, shell surfaces damaged by microborers appear chalky and hummocky; at higher magnifications these irregular chalky surfaces are in fact bored and pitted. Where excoriation fields extend axially down the surface of the spire, a trench is formed which superficially resembles a repaired fracture (see center of specimen in Pl. 1, fig. 3). In the tabulation of the frequency of repaired crab damage, care must be exercised not to confuse repairs with excoriation trenches.

Microborings in the odostomes from Georgia are usually subcircular to elliptical holes, 1 to 6 μm in diameter, which enter the shell surface in most cases at oblique angles (Fig. 3, B). The microborings are associated with elongate striations having about the same range of diameters as the holes (Fig. 3, A and C). This may indicate that the microboring organism was in fact semi-endolithic, with part of the creature anchored within the shell surface and part lying on the surface of the shell. These attributes suggest that the microborer responsible for these holes and striations was an alga (see Boekschoten, 1966, 1967). In fact, some odostomes observed under low magnification in reflected light were covered with green material reminiscent of algal coatings on stone walls. Although the identity of the microborer is undetermined, similarities in size and morphology between these traces and the straight microborings made by endolithic cyanophytes, such as *Hyella,* are

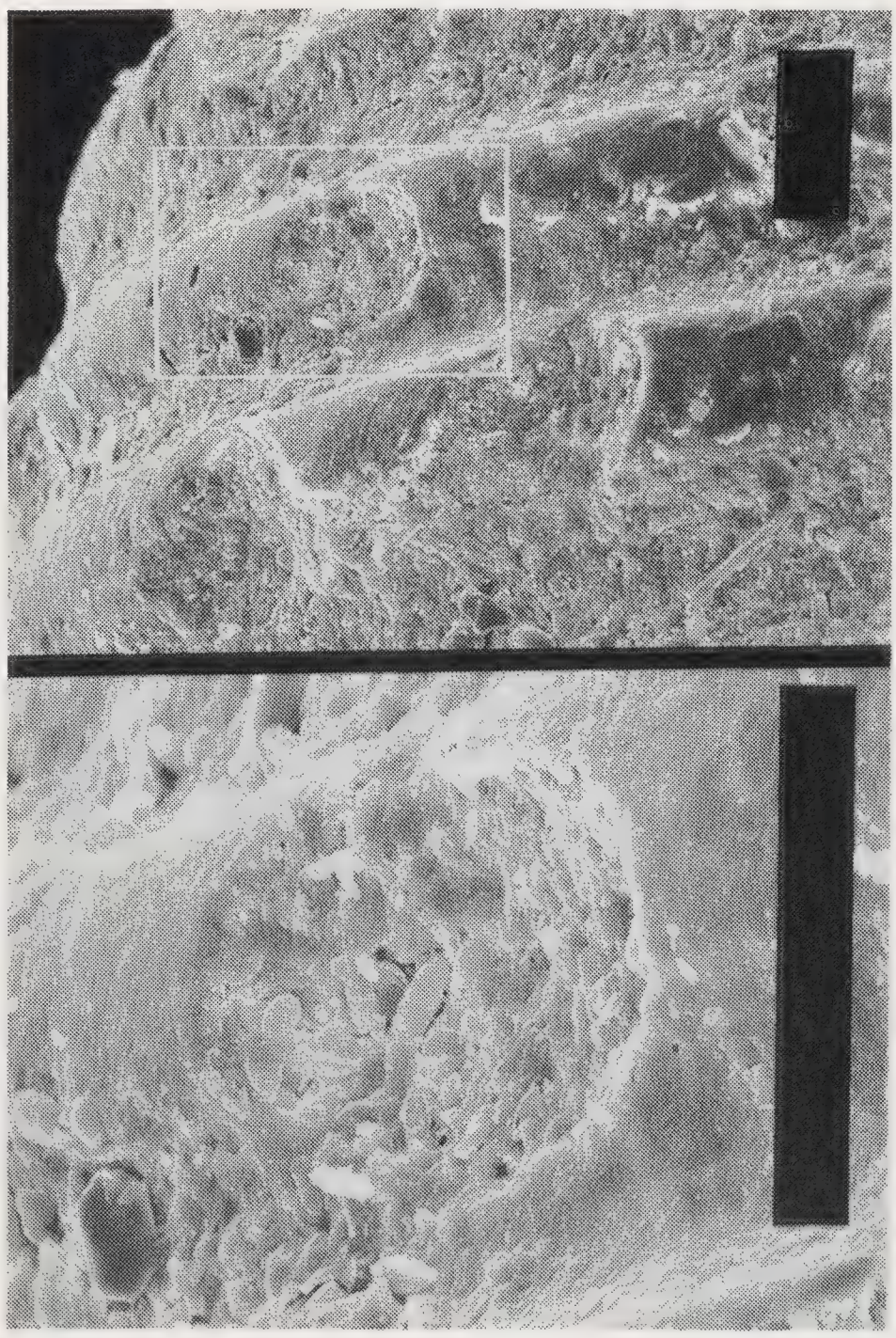

Figure 4. Rimless microscopic pit on *Odostomia impressa* shell. Notice hummocky floor of pit and lack of bordering rim (*cf.* Fig. 5). (Bar scale represents 100 μm.)

noteworthy (see Golubic *et al.*, 1975, Fig. 12.5).

A second population of microborings with much narrower openings, about 0.5 μm in diameter, was observed under the highest magnifications used in scanning the surface of shells. A small cluster of these borings and pits can be seen in the lower left-hand corner of Fig. 3, C. These extremely small microborings may be attributable to endolithic fungi that are in some way associated with the boring algae described earlier (see Golubic *et al.*, 1975, Fig. 12.4, A).

Tabulation of the frequency of microborers in *O. impressa* was not possible. However, it is estimated that over one-half of all specimens, including fragments, from the two largest samples from Georgia had more than half of their surface areas infested with microborers, as evidenced by chalky, pitted microtopography observed at low magnification using a dissecting microscope.

Gastropod Borings. — Signs of predation caused by gastropods in odostome shells from Georgia were very rare; no examples of such borings were found in the Virginia samples. Many of the borings are not unlike miniature versions of the holes made by naticid snails (see Boucot, 1981, Figures 181, 182), but are only about 0.25 to 0.5 mm in outer diameter. Some of the holes counted as gastropod borings, however, departed significantly from the well developed parabolic configuration of true naticid borings in having rather irregular shapes, perhaps due to boring through thin shell substrates. Some of these holes actually may have been caused by non-biogenic processes, such as the chemical dissolution of the shell, so that the counts tabulated in Table 3 should be regarded as liberal estimates. The identity of the predatory snail responsible for the unequivocal borings has not been established, but juvenile naticids may be the culprits. However, owing to the oyster bank habitat, epifaunal muricids should not be ruled out (Robert Robertson, person. comm., 1982). There seems to be little difference in the frequency of bored shells between the lower Wilmington River and Wassaw Sound localities, considering the largest samples only.

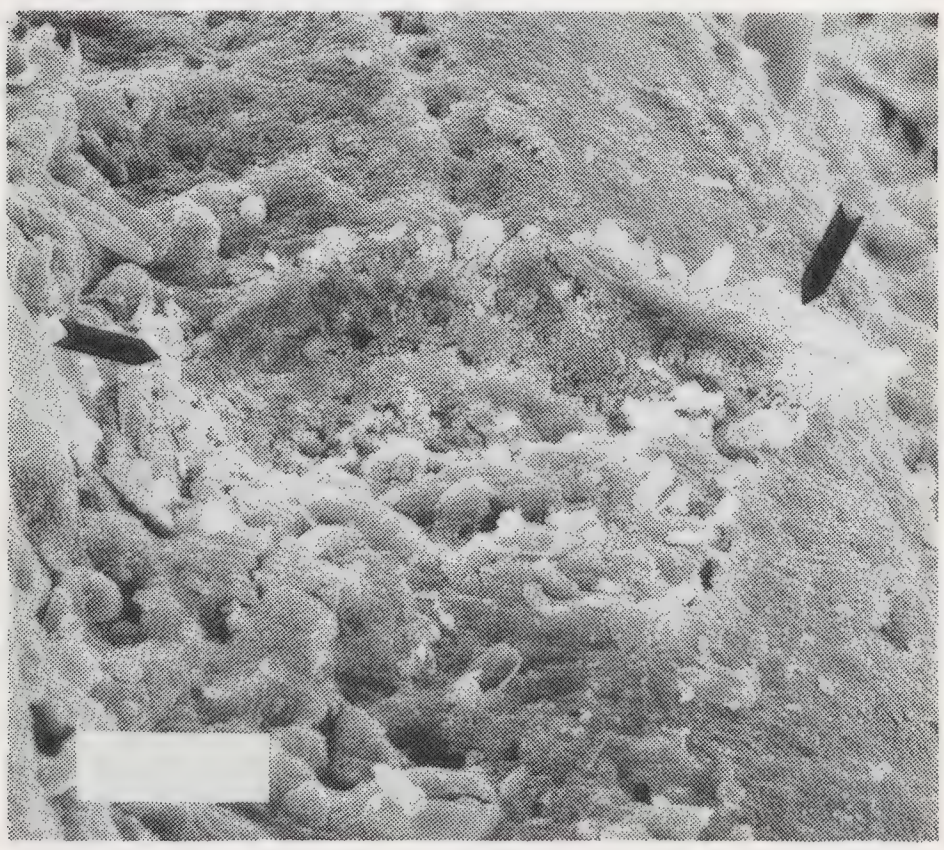

Figure 5. Rim-bearing microscopic pit on *Odostomia impressa* shell. Arrows point to powdered shell material forming the discontinuous rim. (Bar scale represents 20 μm.)

Bryozoan Borings. — Whereas none of the odostomes from Georgia showed signs of having been bored by bryozoans, many of the Virginia specimens had been infested on their apical regions by *Electra* sp., a boring cheilostome (see Boekschoten, 1967, Fig. 34). Odostome spires heavily pitted with *Electra* borings superficially resemble spires with extensive algal excoriation damage. In a few of the specimens from Virginia, *Electra* zoaria were still adhering to the shells, thereby allowing the definite identification of this source of shell damage in the subtidal samples.

Pits of Unknown Origin. — A number of the odostomes from Georgia featured microscopic pits located on the surfaces of whorls above the body whorl. Two varieties were observed: 1) subcircular to elliptical pits lacking rims and having hummocky floors (Fig. 4); and 2) circular to subcircular pits with rims and more or less smooth, parabolic floors (Fig. 5). Rimless pits are about 80 to 100 μm in diameter, and grade into trench-like excoriated areas; the pits with rims seem to be slightly smaller in average diameter.

Although the origin of the pits is unknown, there are two possible causes. The microtopography within the rimless pits is very similar to that of shell surfaces infested with algal microborings, and the same endolithic organisms may be responsible for these circular traces. The rim-bearing pits, however, may result from the handling of the spire of *O. impressa* during crab attacks, with the pits representing the points of im-

pact of serrations located along the inner edges of endopodites and dactylopodites of a cheliped with the shell surface. This would account for the rim of powdered shell material surrounding this type of pit (see Fig. 5). No attempt was made to measure the frequency of pits or pitted shells.

V. DISCUSSION AND CONCLUSIONS

The study of biogenic shell damage is one of the only methods available to the paleosynecologist that can be used in establishing the kinds of ecological associations which existed among fossil species within paleocommunities. Inferential methods, such as deducing the presence of algal-covered substrates from the presence of the shells of grazing gastropods, are much less reliable owing to dependence on taxonomic uniformitarianism and absence of physical evidence in the form of traces (*e.g.*, "addition by inference" in analysis of paleocommunities described by Kauffman and Scott, 1976, p. 17). Evidence of predation, parasitism, post-mortem infestation of skeletons, and competition for space among epilithic organisms may be obtained by carefully observing the condition of fossil shells in the course of assemblage analysis (see Boekschoten, 1967; Bishop, 1975; Golubic *et al.*, 1975; Liddell and Brett, 1982; Schindel *et al.*, 1982). Traces on shells may in some instances be the only surviving evidence of predators or encrusters that lacked skeletal hardparts (*e.g.*, *Polydora* borings in Neogene bivalves). Notwithstanding, problems arise even when traces are plentiful in the identification of ecological associations within very old paleocommunities, wherein shell damage cannot be related with certainty to the predators or encrusters responsible by making a direct comparison with modern community structure. The best evidence of ancient ecological associations will always come from the observation of organisms in physical contact in fossil assemblages directly indicating an interrelationship (Ager, 1963, Chapt. 15).

Not only are large shells of fossil mollusks useful in establishing the existence of ecological associations in ancient communities, but so are the typically more numerous shells of small sizes. Because smaller shells often occur in very large numbers in marine and estuarine fossil deposits (*e.g.*, *Gemma gemma* (Totten) in sandy paralic Pleistocene deposits in North Carolina, described by Miller, 1982), they are more useful than larger, less abundant fossils in statistical analyses of predation or infestation frequency. Through studies of shell damage in modern mesoscopic mollusks, the interpretation of such damage in fossil material can be advanced, at least in Cenozoic examples.

Odostomia impressa is a well known ectoparasite on *Crassostrea virginica* (Gmelin) (Allen, 1958; Wells, 1959, 1961; Robertson, 1978). It occurs in large numbers in shelly sediments surrounding modern oyster banks in coastal Georgia. Nearly all of the shells studied from the Wassaw Sound area showed signs of repaired or unrepaired damage caused by crabs, and most fragmental specimens and shell shards are the result of predation by crabs. At least 25 percent of odostomes in this area of the Atlantic Coast are successfully attacked and killed by crabs. This im-

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PLATE 1

Condition of shells and fragments of *Odostomia impressa* from the lower Wilmington River-Wassaw Sound estuary, Georgia (see Table 2).

Figures

1. Whole shell showing unrepaired damage to the outer lip of the body whorl. Notice arcuate outline of the fracture. (Bar scale represents 1 mm.)
2. Oblique view of a whorl shard. (Bar scale represents 400 μm.)
3. Decollate shell with both the apical and apertural areas broken away. (Bar scale represents 400 μm.)
4. Apical fragment showing peeling beyond the penultimate whorl. This degree of damage was almost certainly fatal to the snail. (Bar scale represents 1 mm.)
5. Apertural fragment. (Bar scale represents 400 μm.)
6. Repaired apertural damage, of the type shown in fig. 1. Arrows point to the fracture line. (Bar scale represents 400 μm.)

PLATE 1.

portant source of mortality in intertidal populations of *O. impressa* has not been previously reported in the literature on pyramidellids. The likely predator on *O. impressa* is the mud crab *Panopeus herbstii* H. Milne-Edwards, 1834 (R. W. Frey, person. comm.). This small, secretive xanthid is very abundant in oyster banks in Georgia, and is associated with the crabs *Sesarma* and *Uca* near the landward edges of the banks. *Panopeus herbstii* is a trophic generalist, feeding upon a wide range of intertidal organisms including young oysters, barnacles, and odostomes; it is in turn preyed upon by raccoons and fish, and probably by birds (see Williams, 1965, p. 196-198). The discovery that a xanthid, probably *P. herbstii*, preys on odostomes is of ecological interest as it demonstrates for the first time how *O. impressa* fits into the food chain of intertidal oyster banks: *O. impressa* and *C. virginica* are associated in a parasite-host relationship, and *P. herbstii* and *O. impressa* appear to be linked in a loose predator-prey association (Fig. 6). Scavengers and decomposers, as usual, reclaim the leavings. Although a few individuals of *O. impressa* in the Virginia samples had been nipped by crabs, it appears that crabs may be far less important as predators on odostomes in subtidal environments than on intertidal banks. This preliminary finding could be tested by comparing relative incidence of predation by crabs within the *same* locality along a bathymetric gradient.

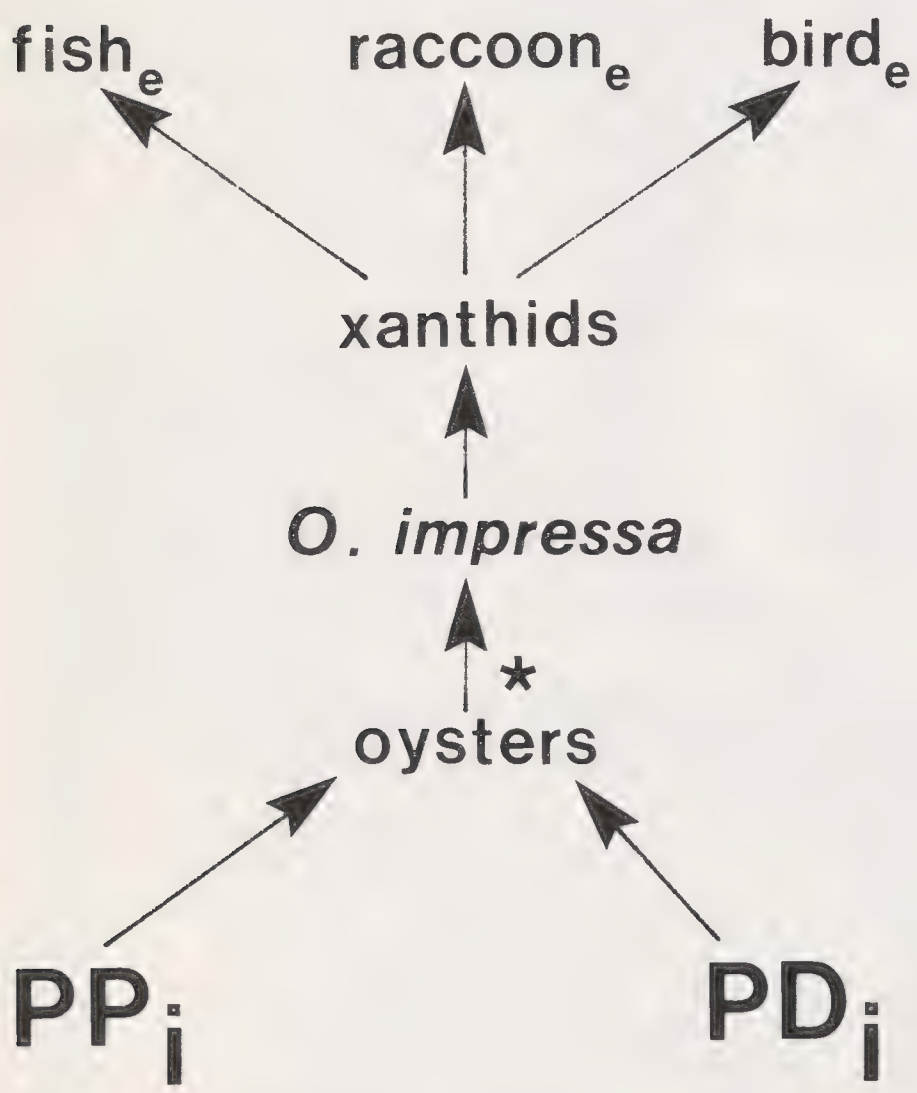

Figure 6. Idealized branch of an intertidal consumer food chain showing the position of *Odostomia impressa* in the trophic structure of oyster bank communities. PP_i = imported phytoplankton from the open estuary and ocean; PD_i = imported plant detritus from salt marshes; $fish_e$ = export in form of fish predator feeding on oyster bank at high tide; $raccoon_e$ = export in form of raccoon feeding at low tide; $bird_e$ = export by birds feeding probably at low tide; * = parasitic relationship. Recuperator organisms are not shown.

The chalky appearance of many of the odostome shells from Georgia is the result of algal excoriation. It is probable that much of the shell damage in estuarine fossil deposits usually attributed to chemical dissolution of $CaCO_3$ (Wiedemann, 1972) is actually caused by infestation by endolithic and semi-endolithic algae, both during life and following the death of the host mollusks. It is now known that microboring organisms and their traces can be used as indicators of paleodepths, bathymetric distribution being controlled by light penetration and water supply. The microborings in the odostomes from Georgia are morphologically very similar to the straight cyanophyte borings typical of the lower intertidal zone (Golubic *et al.*, 1975, p. 234-242).

Minor traces in the samples from the Wassaw Sound area included rare gastropod borings and microscopic pits. The pits are of two varieties with two different possible origins: 1) rimless pits with hummocky floors, which may be caused by algal microborers in the early stages of shell surface infestation; and 2) slightly smaller pits having rims made of powdered shell material, which could have been made by the impact of strongly-toothed crab claws with the surface of odostome shells during attacks.

Many of the Virginia specimens, used as comparative material, also had what appeared to be excoriated spires. On close inspection it was found that this was the result of borings by the cheilostome bryozoan *Electra*. None of the specimens from intertidal banks in Georgia featured this type of shell damage.

In conclusion, mesoscopic shells represent an abundant but little used paleoecologic resource for studies of biogenic shell damage both in modern shelly deposits and in fossil assemblages. The large numbers in which these small mollusks sometimes occur make them particularly useful in statistical comparisons between localities along environmental gradients within the same general area, in comparisons between different major environments, and in comparisons of fossiliferous beds stacked in stratigraphic sections. Biogenic shell damage provides evidence of the ecological interactions between species and may afford the only clues as to the existence of soft-bodied organisms in ancient communities. Traces of predation and parasitism in shells also should be of interest to the neontologist because they provide evidence of the position of mollusks in the trophic structure of modern communities by indicating interactions between species that are very rarely observed by the field ecologist. Just as in Sherlock Holmes' admonition of Dr. Watson, in which the master of deduction demonstrates to his colleague the means of reading a man's profession from the condition of his hands, trouser-knees, and shirt-cuffs, ecologists and paleoecologists should learn to "read" something of the ecologic role of mollusks from the condition of their shells.

VI. ACKNOWLEDGMENTS

This study was begun during a visit to the University of Georgia Marine Extension Service, located at Skidaway Island, Georgia, which was supported by a grant from the Administrators of the Tulane Educational Fund, expedited by Dr. Emily H. Vokes (Tulane University). Mr. James P. Whitcomb (Virginia Institute of Marine Science) supplied the samples from the James River, Virginia, along with detailed descriptions of the condition of sample localities. Mr. W. P. S. Ventress of Chevron Oil Company gave permission to use Chevron's scanning electron microscope facility in New Orleans, and Mr. Dennis Greig skillfully operated the microscope and prepared the micrographs. Mrs. Elizabeth Seale typed the manuscript.

The constructive criticism of this paper by Dr. Robert Robertson and Dr. Geerat J. Vermeij is greatly appreciated.

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REVIEW

THE ABYSS OF TIME: Changing Conceptions of the Earth's Antiquity after the Sixteenth Century, by Claude C. Albritton, Jr. Published by Freeman, Cooper and Company, San Francisco, California, 1980, 251 pp., 29 figs., $12.75

Professor Albritton opens this volume with the statement: "I am confident that someday the concept of geological time will be acclaimed as one of the more wonderful contributions from natural science to general thought." Thus, he introduces his fascinating history of Man's search through the centuries for the answer to the fundamental question "How old is the Earth?"

In his own pursuit of the concept of geological time, Claude accompanied by his wife Jane (to whom this book is dedicated) has sought to retrace the footsteps of the classic writers who have observed the rocks of the crust and have recorded their thoughts on the antiquity of these rocks. His travels have taken him throughout the world and have added much to his insight about his subject. Included are such diverse places as Cretaceous outcrops near Glen Rose, Texas, the Isle of Malta, and the railway station at Capri.

Professor Albritton traces the changing perspective of geological time from Nicolaus Steno to Arthur Holmes. Among those whose contributions to the temporal history of the Earth are discussed are Robert Hooke, Thomas Burnet, Benoit de Maillet, the Comte de Buffon, James Hutton, John Playfair, William Smith, Johann Gottlob Lehmann, Giovanni Arduino, Abraham Gottlob Werner, Adam Sedgwick, Roderick I. Murchison, Georges Cuvier, Charles Lyell, George Poulett Scrope, Louis Agassiz, Charles Darwin, Lord Kelvin, Alfred R. Wallace, Thomas C. Chamberlin, Ernest Rutherford, John Joly, and others. This is far more than merely a history of geological time. The work of each individual is treated in clear, readable prose with a modern, fresh evaluation of his contributions. The book serves as a thorough review of the history of historical geology from the mid-seventeenth century to the mid-twentieth century. Thus, it is a valuable resource and reference for all geologists and historians interested in the development of historical geology.

In his concluding chapter, Professor Albritton considers the current movement to force our preparatory schools to teach evolution theory and creation theory with "reasonably equal emphasis". He observes, "One can only conclude that some creationists, recoiling from the fearsome prospect of time's abyss, have toppled backward into the abyss of ignorance."

This masterful work is highly recommended reading for all geologists. Surely the *Abyss of Time* could not be surpassed as an answer to the "abyss of ignorance."

—H.C.S.

VOORTHUYSENIELLA (MICROPROBLEMATICA) FROM THE SUBSURFACE EARLY NEOGENE OF THE LOUISIANA CONTINENTAL SHELF

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Representatives of the genus *Voorthuyseniella* Szczechura (1969) were discovered in ditch-cutting samples obtained from a well drilled in a nearshore East Cameron location on the Louisiana continental shelf. The section penetrated was the *Lenticulina macomberi* interval (= *Robulus* 43 interval of Gulf Coast terminology *sensu* Skinner and Steinkraus, 1972). The interval may be equated with the planktic foraminiferal zone N8 (Blow, 1969) of early Miocene age. One *Voorthuyseniella* specimen was obtained from each of three samples in the 500 foot section examined. This report documents for the first time the Miocene occurrence of this problematic genus from the Gulf Coast area.

An alternating series of siltstones and fine grained sandstones characterises the penetrated section. This sequence yielded a rich and diverse (>50 species) foraminiferal fauna. The microfauna within this interval exhibited the following composition ranges: Textulariina 14-18%, Miliolina 3%, and Rotaliina 79-83%. The planktic constituent was reasonably stable throughout the interval and comprised an abundance range of 16-18% of the Rotaliina component. The microfaunal composition and character indicates a stable depositional environment characterized by middle to outer shelf (300′-600′) paleobathymetries.

Although the poorly preserved specimens retrieved from this well bore preclude definitive assignment to any formal species group, some systematic relationships may be suggested. Until these relationships can be established, however, the present specimens are left in open nomenclature. Greek alphabet designations are used in this report due to the fact that since the first description of a *Voorthuyseniella* specimen as *Lagena* - *x* by Voorthuysen (1949) authors have made free use of both alpha and numeric designations for specimens in open nomenclature (*e.g.*, Keij (1970), sp.A, sp.B, sp.C; Haman (1978), sp.1, sp.2, sp.3). Repetition of these designations prove to be confusing in any taxonomic treatment. Test orientation, morphologic terms and measurement terminology used in this article follows Haman (1978, fig. 2).

VOORTHUYSENIELLA sp. *α*
Plate 1, figs. 1-6

Description: Test free, unilocular, calcareous, imperforate, longer than high, almost as wide as high, slightly asymmetrical in side view (pl. 1, figs. 2, 6). Test widest at or just below the middle of the camera when viewed from either lateral aperture (pl. 1, figs. 1, 3); exhibiting symmetrical cameral inflation when viewed from above (pl. 1, fig. 4). Tubus generally flat but slightly raised towards both lateral apertures; widest at the middle, tapering slightly to either end (pl. 1, fig. 5). Porta elongate ovate (0.19mm × 0.08mm), aligned in plane of greatest test length; set in depression (0.22mm × 0.10mm) at top of camera (pl. 1, fig. 4). Tubus pore elliptical (0.08mm × 0.04mm), situated midway between the lateral apertures and in line with them (pl. 1, fig. 5). Lateral aperture A circular to subcircular with cameral extension over the upper margin (pl. 1, fig. 1). Supra apertural flap visible above the cameral extension (pl. 1, figs. 1, 4). Lateral aperture B circular, surrounded by a rim, varying in width from 0.015mm to 0.032mm (pl. 1, fig. 3). Internal cameral structure not determined. Test surface rough and pitted, camera slightly smoother than tubus area.

Dimensions: Maximum length 0.38mm, maximum width 0.25mm, height 0.29mm.

Locality: Well cuttings sample 12, 790′ (specimen illustrated on pl. 1, figs. 1-5); well cuttings sample 13,180′ (specimen illustrated on pl. 1, fig. 6); East Cameron area, offshore Louisiana.

Stratigraphic Level: Early Miocene, *Lenticulina macomberi* interval.

Remarks: These forms exhibit marked morphologic similarities to *Voorthuyseniella griegi*, which has been reported from the subsurface Pleistocene of the Southwest Pass area (Haman, 1978), and from the early Holocene of Mudlump 90, Mississippi Delta area (Haman, 1981). If the present forms are conspecific with *V. greigi* a stratigraphic range extension for this species is indicated. Unfortunately, the preservation

of the Miocene individuals has resulted in the modification or obliteration of certain of the original morphocharacter configuration. This is particularly evident with the nature of the porta. The porta of *V. greigi* is subcircular to ovate, whereas in the present specimens it is distinctly elongate, which is probably the result of test dissolution. However, it is this discrepancy which precludes the definitive assignment of the present forms to *V. greigi*.

VOORTHUYSENIELLA sp. β
Plate 1, figs. 7-11

Description: Test free, unilocular, calcareous, imperforate, slightly longer than high, as wide as high, slightly asymmetrical in side view (pl. 1, fig. 8). Test widest around the middle of the camera when viewed from either lateral aperture (pl. 1, figs. 7, 9); displaying uniform cameral inflation when viewed from above (pl. 1, fig. 10). Tubus flat at center, around the tubus pore, becoming higher towards both lateral apertures (pl. 1, fig. 8). Tubus generally equidimensional, only slightly wider at A lateral aperture end (pl. 1, fig. 11). Porta elongate ovate (0.15mm × 0.09mm), set in a bevelled depression (0.20mm × 0.10mm) at top of camera (pl. 1, fig. 10). Tubus pore elliptical, irregular (0.12mm × 0.06mm), situated between the lateral apertures and in line with them (pl. 1, fig. 11). Lateral aperture A subcircular with cameral extension over the upper portion (pl. 1, fig. 7). A thin flap present above the cameral extension (pl. 1, figs. 7, 10). Lateral aperture B circular, surrounded by a partially eroded rim approximately 0.01mm in thickness. Internal cameral structure not determined. Test surface pitted and rough, features which are more evident on the tubus than on the camera. Camera surface fractured.
Dimensions: Maximum length 0.35mm, maximum width 0.30mm, height 0.32mm.
Locality: Well cuttings sample 12,670′, East Cameron area, offshore Louisiana.
Stratigraphic Level: Early Miocene, *Lenticulina macomberi* interval.

Remarks: This specimen is a problematic form insofar as it displays morphocharacters reminiscent of both *Voorthuyseniella baileyi*, reported from the early Holocene of Mudlump 90 (Haman, 1981), and from the subsurface late Pleistocene of offshore Texas (Haman and Kohl, 1976) and *V. greigi*. It is not possible however, due to the preservation, to assign this specimen to either of the established species with any certainty. It is conceivable that this specimen may represent an intermediate morphotype between *V. baileyi* and *V. greigi*. If this proves to be the case, and gradation does exist between these two species, *V. baileyi* would be the senior synonym of *V. greigi*, which would become a junior subjective synonym based on pagination in Haman (1981).

In the Gulf Coast province the genus *Voorthuyseniella* is present in Texas, Louisiana, Mississippi, and Alabama, where it stratigraphically ranges from the Eocene to the Modern (Haman, 1977, and this report). It is clear, however, that each new discovery of this genus confuses the systematic relationships between specimens and consequently complicates any taxonomic treatment of the group. This is perhaps only to be expected when the Linnean system of nomenclature is imposed upon an organism about which nothing is known concerning its life mode or its systematic position. Despite these problems it is necessary to document each new occurrence, as done in this article, in an endeavour to solve this problem eventually. Haman (1979) suggested that the general morphologic variation in shape of *Voorthuyseniella* specimens

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PLATE 1

Figs. 1-5	*Voorthuyseniella* sp. α	Well bore sample 12,790′
Fig. 6	*Voorthuyseniella* sp. α	Well bore sample 13,180′
Figs. 7-11	*Voorthuyseniella* sp. β	Well bore sample 12,670′

Figs. 1, 7 Views to lateral aperture A
Figs. 2, 6, 8 Side views
Figs. 3, 9 Views to lateral aperture B
Figs. 4, 10 Portal views
Figs. 5, 11 Views to tubus and tubus pore

(Bar = 50 microns)

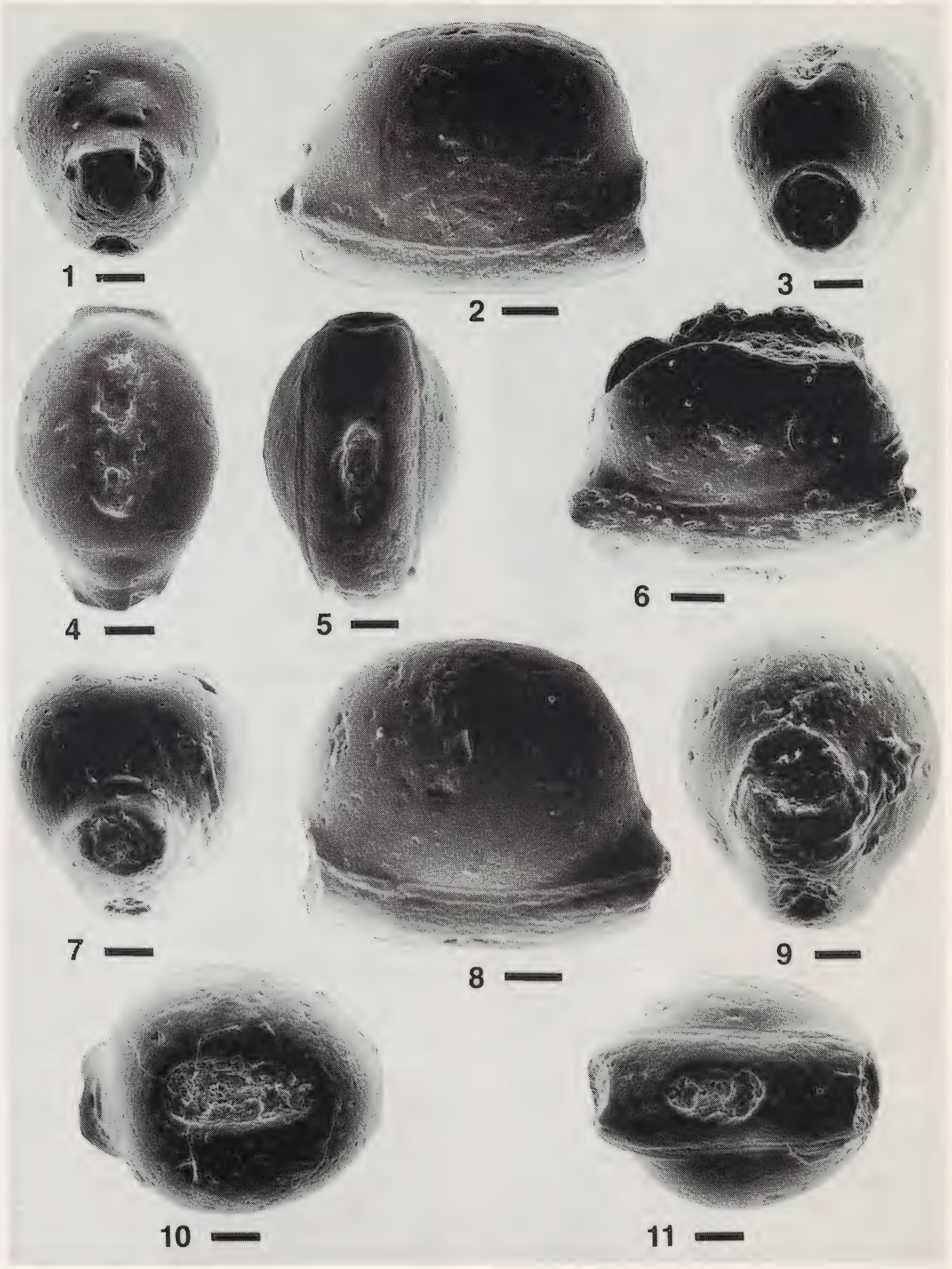

PLATE 1

may be related to paleobathymetric control. The new Louisiana Miocene forms described herein substantiate this concept.

The authors are indebted to J. W. Markham for SEM photography, and to both Chevron U.S.A. Inc., and Chevron Oil Field Research Company for publication permission.

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December 29, 1983

REVIEW

THE ROAD TO JARAMILLO: Critical Years of the Revolution in Earth Science, by William Glen. Published by Stanford University Press, Stanford, California, 1982, xix + 459 pp., 36 figs., 71 photographs, $37.50

This book is the exciting story of the discoveries that produced Plate-tectonics Theory during the critical decade, 1957-1966. The author interviewed the important contributors to this theory and as a result is able to include personal relationships, the role of institutional support, rivalries and frictions between and within research groups and other human factors based on the recollections of the principal participants.

Many individuals, working on once seemingly unrelated problems of rock-dating, geomagnetic polarity reversals, deep-sea cores, and seafloor spreading, have contributed to what has now become established structural theory. The volume takes its name from Jaramillo Creek in New Mexico where rocks were collected which when dated produced the evidence for a new polarity event.

This volume is divided into three parts, title *I. Building the Hourglass: Young-Rock Potassium-Argon Dating, II. Uncovering the Key: Geomagnetic Polarity-Reversal Scales,* and *III. Turning the Key: Applying the Scale.* These are followed by three appendices, notes, references, and the index.

Historians can be grateful that these human events have been recorded while still fresh in the minds of living individuals. It adds much to the understanding of twentieth century geology to have this record.

—H.C.S.

A METHOD FOR THE EXAMINATION OF THE SAME NANNOFOSSIL SPECIMENS FROM THE LIGHT MICROSCOPE TO THE SCANNING ELECTRON MICROSCOPE.

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Techniques are described in the literature for the examination of the same calcareous nannoplankton specimens by both light and scanning electron microscopy. Disadvantages that I have observed with these methods include time consuming coordinate systems, the loss of specimens during the procedure, and the initial examination starting with the scanning electron microscope (SEM) rather than with the light microscope (LM). The initial study of specimens with the light microscope is advantageous because of the much larger LM field of view that enables one to easily locate rare species in the sample. The method described below is the only one that I have found to be satisfactory for routine use. It is similar to the preparation technique described by Moshkovitz (1974, pp. 145-147), in that transmission electron microscope copper grids are used. The method described herein was developed independently, however, and is more easily and effectively implemented. It may be duplicated by proceeding as follows:

With a capillary tube, uniformly spread a drop of centrifuged nannoplankton suspension across a clean 12mm diameter circular cover slip. Allow the suspension to dry slowly by holding it above a hot plate set at approximately 200° F. With sharpened stainless steel tweezers, place four 200 mesh, coordinate-type transmission electron microscope copper grids with the polished side up on the cover slip, being careful not to disturb the dried nannoplankton suspension. Attach the grids onto the surface of the cover slip by "painting" the edges of the grids and the cover slip with Elmer's glue. This step is most easily done by using a 000 brush under a stereo-binocular microscope. When the glue is sufficiently dry, gently press the outer edges of the copper grids to the surface of the cover slip with sharpened tweezers to ensure a firm contact.

Next, place about eight drops of Elmer's glue in a circular pattern on a glass slide. Every drop should be just outside the edge of a 12mm diameter circle (Figure 1). A clean 12mm circular cover slip may be used

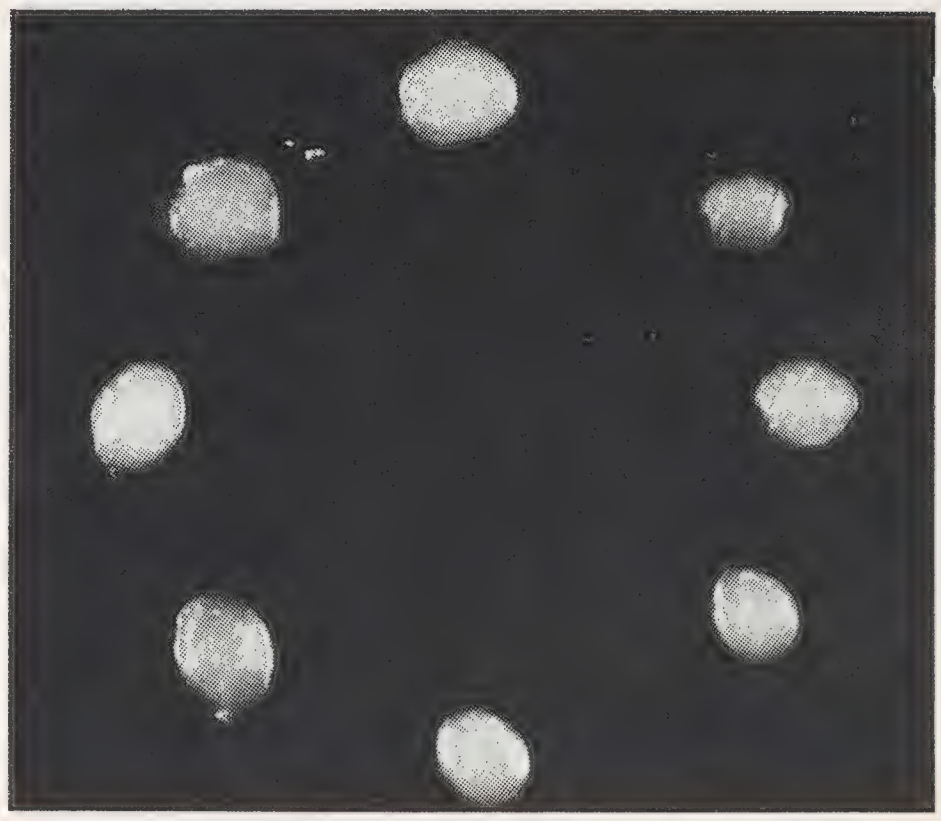

Figure 1: Droplets of Elmer's glue on a glass slide.

for positioning the drops of glue. Remove the clean cover slip, and when the glue droplets have dried, place a drop of immersion oil in the center of the circle of glue droplets. Position the prepared cover clip, with its attached grids facing toward the glass slide, within the circle of dried glue drops, and use the immersion oil as a mounting medium (Figure 2). The droplets of dried glue prevent the cover slip from sliding about on the glass slide as traverses are made across the cover slip during examination with the LM. Normal nannoplankton investigation can now proceed using a coordinate system with the grids (Figure 3). Individual specimens can be identified, photographed, and their location can be recorded for SEM work. Because a Zeiss photomicroscope was used in my work, the reverse sides of the 35mm negatives were used in printing the LM photomicrographs in order for the material in the LM photomicrograph to have the same orientation as the SEM photomicrograph. This step may not be necessary if other brands of light microscopes are used.

When the LM examination is complete, remove the cover slip from the glass slide and clean it in three baths of xylene and a final bath in Dupont TF solvent (trichlorotrifluoroethane). Using fine-tipped tweezers, lift the cover slip from the glass slide

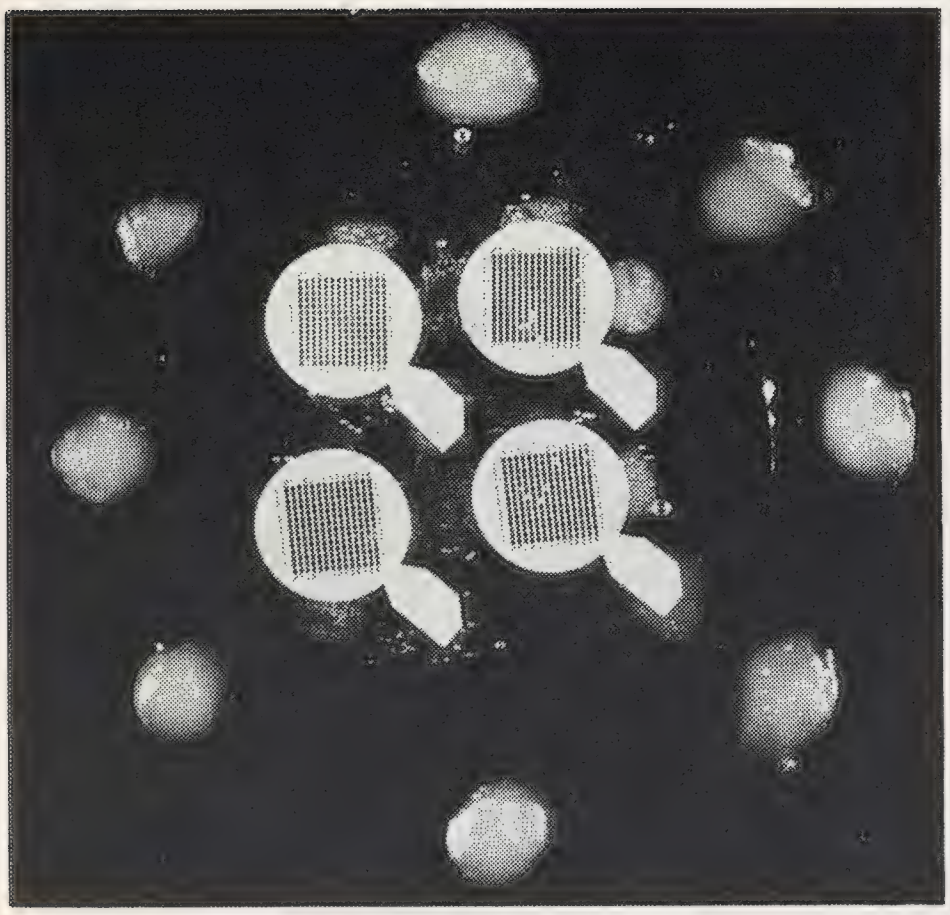

Figure 2: Cover slip with attached prepared grids on glass slide (face down) with immersion oil as mounting medium and held in place by droplets of dried glue.

and submerse it in a small vial or other suitable container filled with the solvents. Gently move the cover slip from side to side for a few seconds in each of the three baths of xylene to remove the immersion oil. Use the Freon TF for the last step to wash away any remaining xylene. In my experience, few, if any, nannoplankton specimens are lost during this process. The glue holding the grids to the cover slip will not be affected by either of the solvents. Next, place the cover slip with the grid side facing upward on an SEM stub, immerse a toothpick or capillary tube in polyvinyl paint, and touch three or four areas of the cover slip and stub with the paint to secure the cover slip to the stub (Figure 4). Dry the paint for approximately one hour on a hot plate at 200° F. A 3/8-inch thick steel plate drilled with 3/16-inch holes was used as a stand to hold the prepared stub upright on the hot plate. This last step is useful since the paint can be scraped away and the cover slip removed from the stub for future LM investigation. An 80 Angstrom thickness of metal is an adequate coating for SEM study of the specimens. Using the coordinates and photomicrographs of specimens taken during the LM examination, the same individuals can be easily located and photographed with the SEM. Remember, if a Zeiss LM is used, the position of the grids is reversed left to right from the light microscope to the SEM.

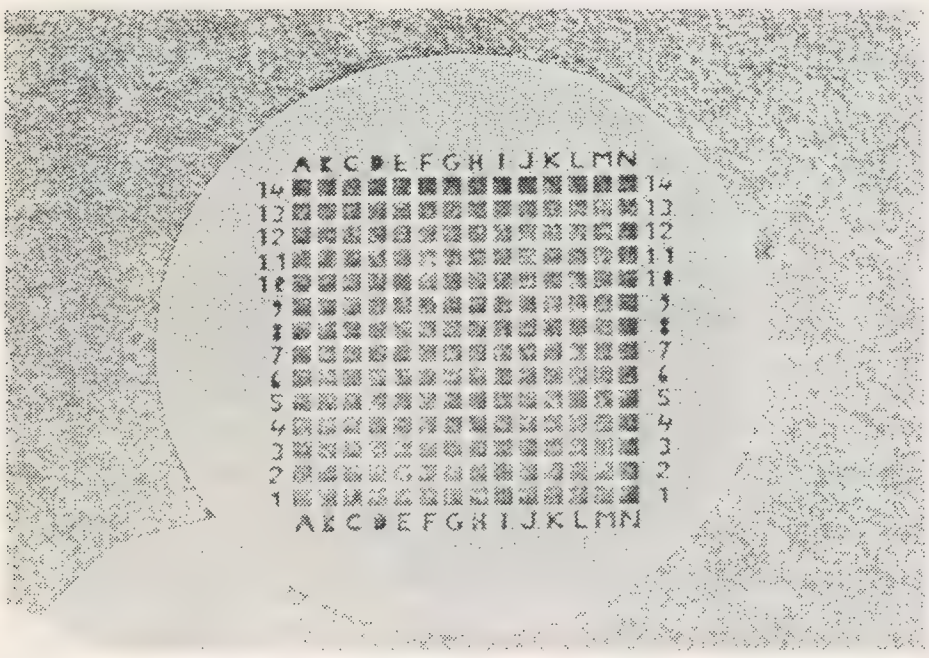

Figure 3: Coordinate-type transmission electron microscope copper grid

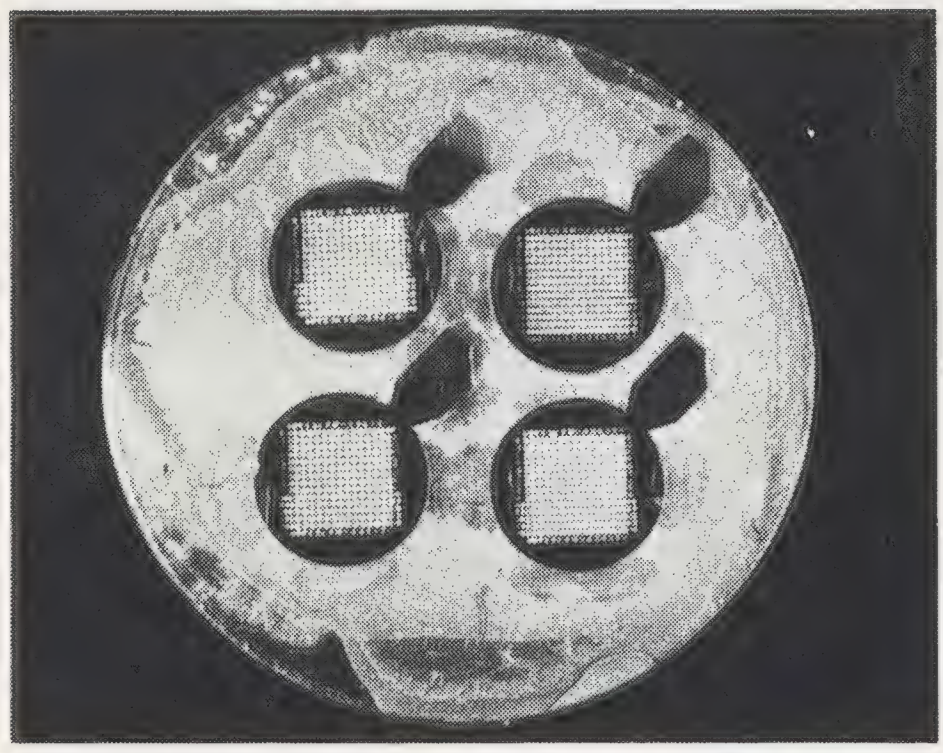

Figure 4: Cover slip with attached prepared grids on SEM stub.

ACKNOWLEDGMENTS

I would like to thank Chevron U.S.A. Inc. for allowing me to publish this article and Dr. W. H. Akers and Mr. W. P. S. Ventress for reading the original draft and offering constructive advice.

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ADDITIONS TO THE TYPHINAE (GASTROPODA:MURICIDAE) OF THE GATUN FORMATION, PANAMA

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The molluscan fauna of the Gatun Formation of Panamá is one of the most completely studied fossil assemblages in the Western Hemisphere (see Woodring, 1957-1982). A total of 396 shelled mollusks have been described from the unit (Woodring, 1982, p. 542) and yet, as a recent collecting trip to Panamá revealed, the treasure trove is far from exhausted.

In 1969 Gertman monographed the muricid subfamily Typhinae in the western Atlantic and he included four species from the Gatun Formation. But new land clearing for rural housing projects in the vicinity of Cativá (ca. 8 km west of Colón) has opened several new, very rich sites and added two new typhine species to the Gatun fauna.

The most exciting, and unexpected, find was a very large (ca. 35 mm in height) *Rugotyphis*, unlike any species known to the writer. That such a large, and moderately common (a dozen specimens in the type lot) species, should have escaped discovery for so long is amazing. The initial discovery was made by Robert H. Stewart, formerly Geologist for the Panama Canal Company (now retired), who remains the leading expert on Panamanian geology and who most graciously not only parted with his specimen but took us to the locality to obtain more.

The second exciting "find" was a species previously not known to occur in the Gatun — *Typhis (Talityphis) alatus* Sowerby, described from the Gurabo Formation of the Dominican Republic. When Gertman did his study he had no material other than the type lot available. But since that time we have collected extensively in the Dominican Republic and now have a number of examples of *T. alatus*. The species is always confined to the deeper facies (Gurabo and an unnamed middle Miocene formation) and has yet to be found in the more shallow facies (Cercado or Baitoa formations). Presumably it is this preference for deeper water that has precluded its appearance in the shallow facies of the Gatun. This would appear to be corroborated by the discovery of a single large specimen of *T. alatus* at Telfers Island, near Colón, in what must be the uppermost Gatun beds yet known, and by extrapolation also the deepest. Unfortunately, this nice theory is upset by the additional discovery of a second incomplete example at TU 1431, near Sabanita, which is not only the earliest Gatun, but also the shallowest water — nearly shoreline, with much fossil wood, oysters, sand-dollars, and other shallow-water indicators.

Another typhine species that occurs in the Dominican Republic, as well as in the Gatun Formation, is *Typhis (Talityphis) obesus*, described by Gabb without precise locality data but now known to be confined (in the Dominican Republic) to the early Miocene Baitoa Formation. Again, this is a good example of facies control, for the Baitoa is extremely shallow-water and the presence of *T. obesus* in both formations is a result of ecology rather than precise time correlation. However, it is curious that the form has not yet been found in the Dominican Cercado Formation, which more nearly correlates with the Gatun in age than does the Baitoa.

One of the localities (TU 1429) did not produce any new typhine species but rather an incredible number (more than 100 in about two hours) of the small *Siphonochelus (Pilsbrytyphis) woodringi* Gertman. This species is known only from the upper beds of the Gatun Formation, near Mount Hope. The type lot contained 18 specimens, all from one locality (USGS 8410 = Woodring 175), which is approximately four kms to the west of TU 1429. Whatever the ecologic conditions were in this small area, they were optimum for *S. woodringi*.

On the basis of the other fauna present at the same locality, it would seem to be deeper water than the usual Gatun Formation, for it is here we have found our only examples of *Gemmula vaningeni* (Brown and Pilsbry). This species is most closely related to the Recent eastern Pacific *G. hindsiana* Berry, which Keen (1971, p. 707) notes is found in depths of 40 to 70 meters. According to Woodring (1970, p. 364) *G. vaningeni* is common only in the Mount

Hope area; he records 27 examples from his locality 175, which as noted above is the type locality of *Siphonochelus woodringi*.

Here we have also collected our only examples of *Sconsia sublaevigata* (Guppy), which Woodring (1959, p. 201) reported as principally occurring near the French Canal, west of Mount Hope. The closely related *S. laevigata* (Sowerby) is abundant in the Gurabo Formation of the Dominican Republic; *S. sublaevigata* was described from the deep-water beds of the Bowden Formation of Jamaica; and the living member of the line, *S. striata* (Lamarck), is particularly common at TU 977, in material from Mudlump 90, off the mouth of the Mississippi River, which is judged to have been deposited at about 70 meters depth (Odé, 1973, p. 89).

The age of the Gatun Formation has yet to be satisfactorily determined. Woodring maintained that the age was middle Miocene noting, however, "it should be understood that the age assignments are Lyellian ages not planktonic foraminiferal ages. For the Neogene of America, planktonic foraminiferal ages are almost invariably too young in terms of Lyellian ages" (1973, p. 454). Only in the last volume of his study did he concede that planktonic foraminiferal dates obtained by workers at the British Museum (Natural History) indicated the Gatun was probably latest Miocene or even possibly early Pliocene (1982, p. 576). He concluded that regardless of the exact age the Gatun is correlative with the Cercado and Gurabo formations of the Dominican Republic, as well as with the shall bed of Bowden, Jamaica.

In this writer's opinion, Brown and Pilsbry were more nearly correct in their early assessment wherein they stated: "On the whole we conclude that the Gatun fauna is slightly later than the Santo Domingo and earlier than the Bowden" (1911, p. 337). The beds of the Gurabo formation have been dated as in foraminiferal zone N. 18 (W. H. Akers, personal communication) and the Bowden shell bed is N. 22 (Lamb and Beard, 1972, p. 32). The Rio Banano Formation of Costa Rica (TU 589), which is probably most nearly correlative with the Gatun has been dated by Dr. Akers (personal communication) as N. 20. Thus, it seems likely that the Gatun is about mid-Pliocene in age.

For the sake of completeness, the entire typhine fauna of the Gatun Formation is reviewed below, even though in some cases there is no new information to add. Complete synonymies are not included, instead the reader is referred to Gertman's monograph.

SYSTEMATIC PALEONTOLOGY

Family MURICIDAE da Costa, 1776
Subfamily TYPHINAE Cossmann, 1903
Genus TYPHIS Montfort, 1810

Typhis MONFORT, 1810, Conchyl. Syst., v. 2, p. 614-615.
Type species: *Typhis tubifer* (Bruguière, 1792), by orig. desig.

Subgenus TALITYPHIS Jousseaume, 1882

Talityphis JOUSSEAUME, 1882, Rev. Mag. Zool., (Ser. 3) v. 7, p. 338.
Type species: *Typhis expansus* Sowerby, 1874, by orig. desig.

Discussion: In their study of worldwide Recent Muricidae Radwin and D'Attilio (1976, p. 201) stated that they believed *T. expansus* Sowerby to be the same species later described as *T. puertoricensis* Warmke, 1964. This would mean that the form usually cited as "*T. expansus*" would have no valid name, which they remedied by proposing the new name *T. perchardei* (*ibid.*, p. 236). This change would have a deleterious effect on the concept of the subgenus *Talityphis*, for *T. puertoricensis* is better assigned to *Rugotyphis* (see Gertman, 1969, p. 153), a very different morphotype, leaving the large group of alate typhines without a name. However, the problem was easily solved by a photograph of the type specimen of *T. expansus* from the National Museum of Wales at Cardiff, which proved the species to be that form so identified by most workers. Photographs of this specimen and a more extended discussion will be given by the writer in another work on the fauna of the Dominican Republic (Vokes, in press).

TYPHIS (TALITYPHIS) ALATUS Sowerby
Plate 1, figs. 1-3

Typhis alatus G. B. SOWERBY I, 1850, Geol. Soc. London, Quart. Jour., v. 6, p. 48, pl. 10, fig. 4.

Typhis (Talityphis) alatus Sowerby. GERTMAN, 1969, Tulane Stud. Geol. Paleont., v. 7, no. 4, p. 159, text fig. 3 (holotype).

Discussion: The usual species of *Talityphis* found in the Gatun Formation is *T. obesus* Gabb. Although many writers have confused it with *T. alatus* the two forms are readily distinguishable and only similar at the subgeneric level. The most immediate apparent difference between the two species is the more extended spire of *T. alatus*, but this is not the most diagnostic feature by which to differentiate the two. In *T. alatus* there is always a large swelling immediately anterior to the tube. Only two other species of *Typhis* have this feature. One is *T. eucteanus*, discussed below, and the second is the early Miocene *T. precursor* Keen and Campbell, 1964, from Colombia. This bulge can be seen in the pictures of the holotype of that species (refigured in Gertman, 1969, pl. 3, fig. 1). The latter species is probably ancestral to *T. alatus*, but differs in having a much shorter siphonal canal.

The specimen figured here (pl. 1, fig. 1) from Telfers Island is a giant, measuring over 40 mm in height, nearly as large as the holotype of *T. precursor* (height 47.5 mm). But it is not unique. An equally large specimen (height 40.3 mm) has been collected in the middle Miocene (N.11) of the Dominican Republic (TU 1249) but the more usual size for the numerous Dominican examples we now have is about 30 mm.

The Telfers specimen was collected by Mr. John Gunter of Panamá City, Panamá, who generously donated his prize to science. The discovery of *T. alatus* in the Gatun is an addition to the Gatun fauna but it is not a range or time extension, for Olsson (1964, p. 141) reported the species from the Picaderos Formation of northwestern Ecuador. Examination of his specimen (USNM 23485) confirmed his identification. The Picaderos is thought to be of approximately the same age as the Gatun.

Occurrence in Panamá: Telfers Island and TU 1431. These represent the highest and lowest Gatun Formation respectively; therefore, Brown and Pilsbry's (1911, p. 354) reference to *T. alatus* may be valid. We have not seen this specimen.

Figured specimens: Fig. 1, USNM 365139; height 40.3 mm, diameter 27.5 mm; locality: Telfers Island, Province of Colón, Panamá. Fig. 2, USNM 365140; height (incomplete) 22.0 mm; diameter 17.7 mm; locality TU 1431. Fig. 3, USNM 323913; height 23.5 mm, diameter 14.6 mm; locality TU 1250 (Dominican Republic).

TYPHIS (TALITYPHIS) OBESUS Gabb
Plate 1, fig. 4

Typhis obesus GABB, 1873, Amer. Phil. Soc., Trans., (N. S.) v. 15, pt. 1, p. 203.

Typhis obesus Gabb. PILSBRY, 1922, Acad. Nat. Sci. Phila., Proc., v. 73, p. 354, pl. 28, figs. 5,6 (holotype).

Typhis (Talityphis) alatus obesus Gabb. WOODRING, 1959, U.S. Geol. Surv., Prof. Paper 306-B, p. 221, pl. 31, figs. 3,4.

Typhis (Talityphis) obesus Gabb. GERTMAN, 1969, Tulane Stud. Geol. Paleont., v. 7, no. 4, p. 160, pl. 4, figs. 1-4.

Typhis obesus Gabb. VOKES, 1979, Tulane Stud. Geol. Paleont., v. 15, no. 4, p. 112.

Discussion: Although this species has been reported from many localities and many different geological levels throughout the Western Hemisphere (see Gertman, 1969, p. 162), most of these identifications prove to be in error and the species has actually only been taken in the Baitoa Formation of the Dominican Republic (the type locality) and the Chipola Formation of Florida (both late lower Miocene in age) and in the Gatun Formation of Panamá. A more complete discussion and reassignment of the various misidentifications will be given in the aforementioned paper on the Dominican fauna (Vokes, in press).

Occurrence in Panamá: TU localities 757, 958, 962, 1431; Woodring locality 136. All in the lower Gatun, near Sabanita and Cativá. Brown and Pilsbry's (1911, p. 354) reference to *T. obesus* from the Gatun locks excavation has not been verified.

Figured specimen: USNM 646220; height 27.5 mm, diameter 23.0 mm; locality TU 757.

TYPHIS (TALITYPHIS) EUCTEANUS Woodring
Plate 1, fig. 5

Typhis (Talityphis) sp. GERTMAN, 1969, Tulane Stud. Geol. Paleont., v. 7, no. 4, p. 160, pl. 5, fig. 1.

Typhis (Talityphis) eucteanus WOODRING, 1970, U.S. Geol. Surv., Prof. Paper 306-D, p. 434, pl. 63, figs. 9, 10.

Discussion: As the specific name implies (*eukteanos* — Greek, tall or slender), this is the most slender of the *Talityphis* species. It shares with *T. alatus* the swelling beneath the tube, but may be distinguished from

that species by its extremely elongated siphonal canal.

All known specimens of *T. eucteanus* have been taken in the lower part of the Gatun. When Woodring described the form he had three specimens and there were three in the Tulane Collection. No new material has been found since that time.

Occurrence in Panamá: TU locality 958; Woodring locality 138f (= TU 757).

Figured specimen: USNM 646221; height 17.7 mm, diameter 9.2 mm; locality TU 958.

Subgenus RUGOTYPHIS Vella, 1961

Rugotyphis VELLA, 1961, Palaeontology, v. 4, p. 376.

Type species: *Typhis francesae* Finlay, 1924, by orig. desig.

TYPHIS (RUGOTYPHIS) STEWARTI
E. H. Vokes, n. sp.
Plate 1, figs. 8, 9

Description: Shell large, stout; early whorls unknown, but presumably a protoconch of one and one-half bulbous whorls; seven post-nuclear whorls. Four varices per whorl, each with a short, sharp spine at the apical end, directed nearly at right angles to the axis of the shell; each varix crossed by about four faint spiral ribs; varical face of two parts: a thickened portion nearer the body, and a thin free-standing flange, crenulated by the spiral ribs and slightly reflected abaperturally; this flange developed only on the body portion of the shell, abruptly truncated at the constriction into the anterior canal. Varical flange with the appearance of having been wrapped over the original varix from behind, especially at the shoulder, with a small fold directed toward the suture, forming a strange gutter-like structure enveloping the shoulder spine and connecting it to the preceeding tube. Terminal varix with a small partition, but none visible on previous varices, perhaps having been decorticated; tubes closer to the preceeding than to the succeeding varix, directed abaxially and abapically. Shell smooth, except for the crenulations of the varices. Aperture ovate-rounded, surrounded by an entire raised rim; anterior canal closed, narrow, almost straight, distal end only slightly reflected.

Dimensions of holotype: height 35.0 mm, diameter 25.2 mm.

Holotype: USNM 365136.

Type locality: TU 1432, Gatun Formation, north side Boyd-Roosevelt Highway, behind Residential Martin Luther King (formerly Palo Quemado), approximately 1.5 km east of junction

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PLATE 1

Figures

1 - 3. *Typhis (Talityphis) alatus* Sowerby
   1. (× 1½) USNM 365139; height 40.3 mm, diameter 27.5 mm
      Locality: Telfers Island, Prov. of Colón, Panamá. Gatun Formation.
   2. (× 2) USNM 365140; height (incomplete) 22.0 mm, diameter 17.7 mm
      Locality: TU 1431. Gatun Formation.
   3. (×2½) USNM 323913; height 23.5 mm, diameter 14.6 mm
      Locality: TU 1250. Gurabo Formation

4. *Typhis (Talityphis) obesus* Gabb
   (× 1½) USNM 646220; height 27.5 mm, diameter 23.0 mm
   Locality: TU 757, Gatun Formation
5. *Typhis (Talityphis) eucteanus* Woodring
   (× 3) USNM 646221; height 17.7 mm; diameter 9.2 mm
   Locality: TU 958. Gatun Formation
6. *Siphonochelus (Pilsbrytyphis) woodringi* Gertman
   (× 2) USNM 365138; height 23.0 mm; diameter 11.2 mm
   Locality: TU 1429. Gatun Formation
7. *Siphonochelus (Pilsbrytyphis) gabbi* (Brown and Pilsbry)
   (× 3½) ANSP 1722 (holotype); height 13.3 mm, diameter 7.6 mm
   Locality: Gatun Lock. Gatun Formation

8, 9. *Typhis (Rugotyphis) stewarti* E. H. Vokes, n. sp.
   8. (× 1½) USNM 365136 (holotype); height 35.0 mm, diameter 25.2 mm
      Locality: TU 1432. Gatun Formation
   9. (× 1½) USNM 365137 (paratype); height (incomplete) 28.1 mm, diameter 27.4 mm
      Locality: TU 1433. Gatun Formation

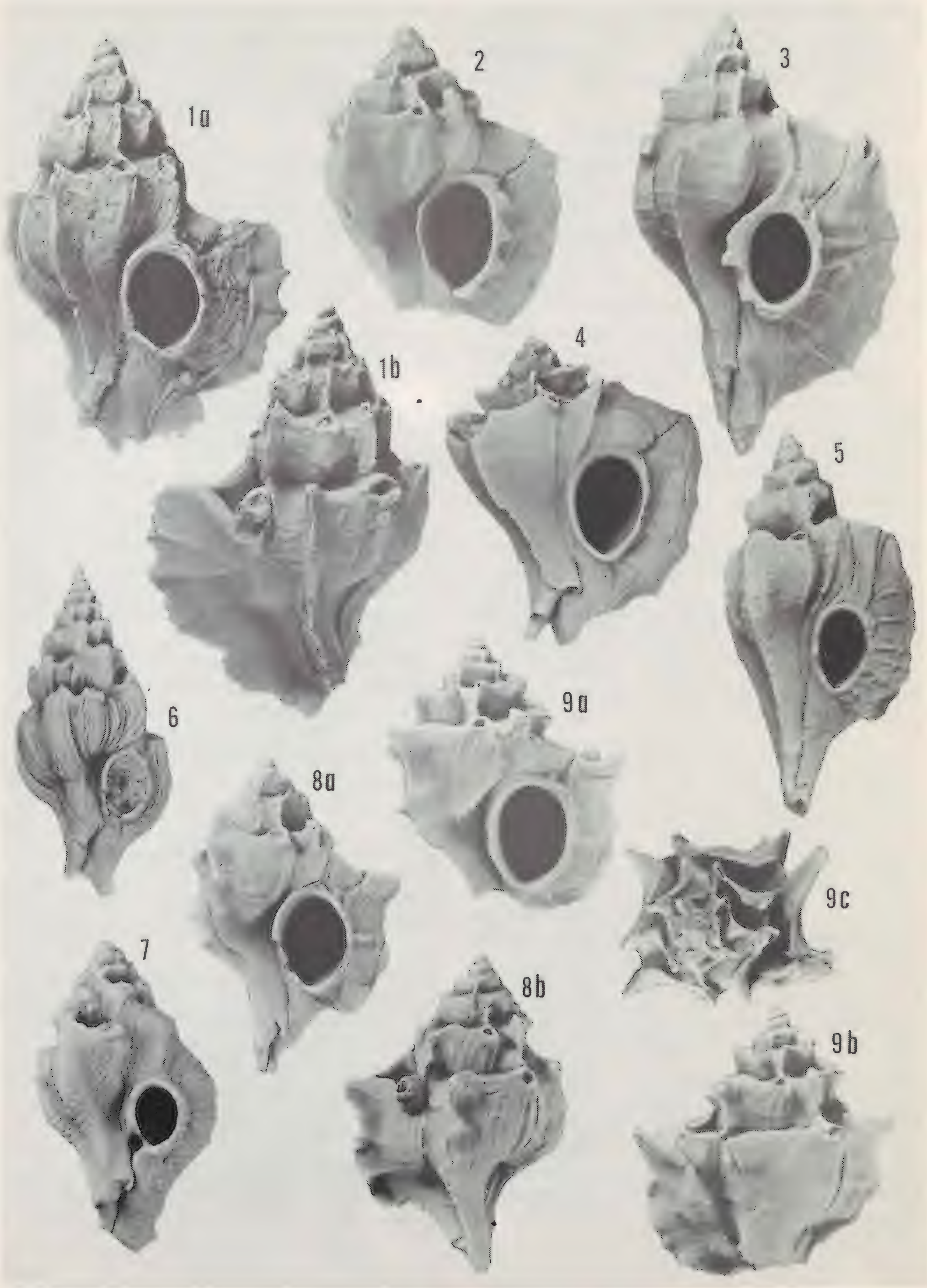

PLATE 1

of road to Refinería Panamá, S.A., at Cativá, Province of Colón, Panamá.

Figured specimens: Fig. 8, USNM 365136 (holotype). Fig. 9, USNM 365137 (paratype); height (incomplete) 28.1 mm, diameter 27.4 mm; locality TU 1433.

Discussion: With the exception of *T. precursor* and the two giant examples of *T. alatus* mentioned above, this is the largest species of *Typhis* yet discovered. It is also totally unlike any other described form, so that comparisons are difficult. In general, its nearest relative seems to be the Recent *T. cleryi* Petit de la Saussaye (see Gertman, p. 154, text fig. 2-holotype) but that species is much smaller (maximum size about 25 mm) and the shoulder spines of *T. cleryi* are recurved adapically, unlike the new species in which they jut out almost at right angles to the body. In addition, the varical flange does not extend past the body whorl onto the siphonal canal as it does in *T. cleryi*. In this respect it more nearly resembles *T. keenae* Gertman, but that species lacks the crenulated free-standing flange, having instead about four distinct recurved spines along the varical edge. The shoulder spine of *T. keenae* is also directed adapically and neither it nor any other species has the peculiar gutter-like fold at the shoulder seen in the new species.

All examples have come from the lowest Gatun beds, and the rather beach-worn condition of the specimens tends to suggest that this species must have lived in extremely shallow water. This is unusual for members of the Typhinae, although the members of *Rugotyphis* do seem to occur in relatively shallow water — *e.g.*, the Chipola Formation of northwestern Florida and the Caloosahatchee beds of south Florida.

As noted in the introduction, this new find is not especially rare. In the type lot there are two specimens from TU 1433 and eight from TU 1432. Another two examples remain in the collection of Robert H. Stewart, for whom the species is named, in honor of his long years of dedication to the geology of Panamá, his many kindnesses over those years to us, and because he collected the type specimen!

Genus SIPHONOCHELUS Jousseaume, 1880

Siphonochelus JOUSSEAUME, 1880, Le Naturaliste, Année 2, no. 42, p. 335.

Type species: "*Typhis avenatus* Hinds" (= *Typhis arcuatus* Hinds, 1843), by orig. desig.

Subgenus PILSBRYTYPHIS Woodring, 1959

Pilsbrytyphis WOODRING, 1959, U. S. Geol. Surv., Prof. Paper 306-B, p. 220.

Type species: *Typhis gabbi* Brown and Pilsbry, 1911, by orig. desig.

SIPHONOCHELUS (PILSBRYTYPHIS) GABBI (Brown and Pilsbry)
Pl. 1, fig. 7

Typhis gabbi BROWN and PILSBRY, 1911, Acad. Nat. Sci., Phila., Proc., v. 63, p. 354, pl. 26, fig. 6.

Typhis (Pilsbrythyphis) gabbi Brown and Pilsbry. WOODRING, 1959, U. S. Geol. Surv., Prof. Paper 306-B, p. 220 (in part only, *not* pl. 32, figs. 2, 3, 5, 7 = *S. woodringi* Gertman).

Siphonochelus (Pilsbrytyphis) gabbi (Brown and Pilsbry). GERTMAN, 1969, Tulane Stud. Geol. Paleont., v. 7, no. 4, p. 179, pl. 7, fig. 4 (holotype).

Discussion: Siphonochelus gabbi was described as coming from the excavations at Gatun Lock, but we have never taken a specimen of the species in Panamá. Our only examples are from TU 967, in the Rio Banano Formation of Costa Rica, which is thought to be correlative in age with the Gatun. Woodring (1959, p. 220) mentions only a single immature specimen in addition to the type from the middle Gatun. All of his other specimens, from the upper Gatun, are a different species, named *S. woodringi* by Gertman.

Occurrence in Panamá: Gatun Lock (Brown and Pilsbry); Woodring locality 147g; both in the middle Gatun Formation.

Figured specimen: ANSP 1722 (holotype); height 13.3 mm, diameter 7.6 mm; locality: Gatun Lock.

SIPHONOCHELUS (PILSBRYTYPHIS) WOODRINGI Gertman
Plate 1, fig. 6

Typhis (Pilsbrytyphis) gabbi Brown and Pilsbry. WOODRING, 1959, U. S. Geol. Surv., Prof. Paper 306-B, p. 220 (in part *not* of Brown and Pilsbry), pl. 32, figs. 2, 3, 5, 7.

Siphonochelus (Pilsbrytyphis) woodringi GERTMAN, 1969, Tulane Stud. Geol. Paleont., v. 7, no. 4, p. 180, pl. 7, fig. 6.

Discussion: This species also has the peculiar "peanut-shell" sculpture of *Pilsbrytyphis*, but in *S. woodringi* it is oriented axially rather than spirally as in *S. gabbi*.

As noted above, this species is confined to the upper Gatun in the vicinity of Mount Hope, but it is extremely abundant in this small area.

Occurrence in Panamá: TU locality 1429; Woodring localities 175, 176, 176a, 177b. All in the upper Gatun Formation.

Figured specimen: USNM 365138; height 23.0 mm, diameter 11.2 mm; locality TU 1429.

ACKNOWLEDGMENTS

John Gunter and Robert H. Stewart, both of Panamá City, Panama, generously donated two of the specimens upon which this work is based. In addition, both provided numerous other material to the Tulane Collections, of fossil and Recent mollusks, and we wish to express our extreme gratitude to these gentlemen. Dr. Myra Keen, Stanford University (Emeritus), did her usual good job of reviewing the manuscript.

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LOCALITY DATA

589. Rio Banano Fm., Rio Banano, north bank, about 0.6 to 0.8 km above the railroad bridge at La Bomba, Limón Province, Costa Rica.

757. Gatun Fm., roadcut on south side of Boyd-Roosevelt Highway at junction of road to Refinería Panamá, S. A., just east of Cativá, Prov. of Colón, Panamá.

958. Gatun Fm., hillslope on east side of road from Boyd-Roosevelt Highway to Refinería Panamá, S. A., about ½ km north of junction, just east of Cativá, Prov. of Colón, Panamá.

962. Gatun Fm., on road to Refinería Panamá, S. A., about one-half km south of the gate, hillcut and fill for new power plant construction (1968), Prov. of Colón, Panamá.

967. Rio Banano Fm., Rio Banano, south bank, just above railroad bridge at La Bomba, Limón Province, Costa Rica.

977. Unnamed post-Pleistocene formation, mudlump no. 90, mouth of South Pass, Mississippi River delta, Plaquemines Parish, Louisiana.

1249. Unnamed formation, roadcut 8.6 km west of the plaza at San Cristóbal, on road to Baní, Dominican Republic (= loc. H-20001, Bermudez, 1949).

1250. Gurabo Fm., Rio Verde, south bank, just above the ford at the crossing of a side road that connects Duarte Highway and La Vega-

Moca Highway, about 10 km north of La Vega, Dominican Republic.

1429. Gatun Fm., construction site, one km southeast of Boyd-Roosevelt Highway, just south of Coco Solo Hospital, Prov. of Colón, Panamá.

1431. Gatun Fm., hilltop construction site, 0.5 km northwest of intersection of Boyd-Roosevelt Highway and road to Puerto Pilon, at Sabanita, Prov. of Colón, Panamá.

1432. Gatun Fm., north side Boyd-Roosevelt Highway, clearing behind Residential Martin Luther King (formerly Palo Quemado), approximately 1.5 km east of junction of road to Refinería Panamá, S.A., at Cativá, Prov. of Colón, Panamá.

1433. Gatun Fm., north side Boyd-Roosevelt Highway, clearing behind Urbanization San Martin, approximately 0.5 km east of junction of road to Refinería Panamá, S.A., at Cativá, Prov. of Colón, Panamá.

December 29, 1983

REVIEWS

LANGUAGE OF THE EARTH, edited by Frank H. T. Rhodes and Richard O. Stone. Published by Pergamon Press, New York, Oxford, Toronto, Sydney, Paris, Frankfurt, 1981, xiii + 417 pp., cloth $35.00, paper $17.50

Language of the Earth is an anthology designed to provide supplementary readings for elementary earth science students. As Professor Rhodes states, with conventional styles of teaching the subject matter all too often emerges as "given, frozen, complete, canned." This book is designed to make earth science more real, meaningful, useful and intelligible by offering selected readings from original authors "to illustrate the scope and range of the science and to convey its flavor and style, rather than catalog its contents; to display all our knowledge as provisional rather than infallible, as refinable rather than complete and finished; to show the inspiration and sweeping implications of earth science, rather than representing it as an isolated area of study."

The readings are well chosen; they illustrate that geologists are human, that geological science is exciting and dynamic, subject to controversy and changing as new discoveries emerge, that there is beauty, humor, poetry, art, intrigue, world history and politics in geology as well as economic benefits. Thus, an overview of earth science is presented which is delightfully readable as much as it is useful. It is highly recommended for students of earth science and for those who wish to browse in a volume which will reveal to them the scope and significance of the geosciences.

FOSSILS: The Key to the Past, by Richard Fortey. Published by Van Nostrand Reinhold Company, New York, Cincinnati, Toronto, London, Melbourne, 1982, 172 pp., illustrated, $24.95

This book is intended to illustrate how fossils can be and have been used to reconstruct the past history of the Earth. It presents paleontology as a living science with changing perspectives on interpretation of the past as new discoveries emerge and are considered. Many of the illustrations in this handsome volume are in color and these are numerous, well selected, and serve more than adequately to depict the panorama of paleontology for the non-technical reader and student.

Beginning with the historical background of paleontology, the author discusses fossilization, utilization of fossils to subdivide and define geological time, concepts of drifting plates, sedimentary processes and features, facies and climatic distributions, reefs, submarine canyons, turbidites, and many other features. Succeeding chapters deal with recognition of fossils, identification, reconstructions of living images from fossil remains, origin and evolution of life, fossils in the service of man (economic importance and usefulness), and how to make a collection of fossils. This work constitutes a short course in the geology of fossils and their role in elucidating geology for the non-technical reader. It is highly recommended for those who wish to gain an overview of fossils and historical geology.

—H.C.S.

NERITA EXUVIOIDES TRECHMANN (MOLLUSCA:GASTROPODA) FROM THE GATUN FORMATION OF PANAMA

EMILY H. VOKES
TULANE UNIVERSITY

Due to their preference for a rocky littoral habitat, examples of fossil nerites rank a close second to hen's teeth. Therefore, it was a pleasant surprise to see a rather well-preserved specimen found in the Gatun Formation of Panama by Robert H. Stewart, formerly geologist for the Panama Canal Company (now retired). First examination of the specimen yielded even more remarkable results for it became obvious that it is not even vaguely related to any New World members of the genus now living but is most closely related to the Philippine *N. exuvia* Linn., a form with extremely heavy spiral cords. The specific name that immediately came to mind was "*exuvioides.*"

A perusal of the literature quickly revealed that not only was the species already described — it had been named *exuvioides* by Trechmann (1935), based upon a single poor specimen from "St. Helene Point" (*i.e.*, Point Saint Hilaire), Carriacou. Jung, in studying the Carriacou fauna, noted that the holotype (which he refigured) is "an incomplete specimen unsuitable as type material" (1971, p. 175) and subsequent collecting has added only one additional fragmentary topotype. The apertural features of the holotype being unknown, the specimen was assigned to the subgenus "*Nerita*?" by Jung. The aperture of the Panama specimen, although not perfect, is sufficiently well-preserved to observe that it is undoubtedly a member of the subgenus *Theliostyla* Mörch, characterized by having pustules on the apertural platform and very fine denticulations on the labial margin.

In the New World there are only three species referable to this subgenus: *N. funiculata* Menke, 1851, in the eastern Pacific; and *N. tessellata* and *N. fulgurans*, both of Gmelin, 1791, from the western Atlantic. All three of these species are similar in appearance with only fine spiral cords and all have a completely different appearance from the heavily ribbed fossil shell.

In the Recent fauna *N. funiculata* and *N. fulgurans* most nearly resemble each other externally, both with a color pattern of indistinct gray and yellow blotches. *Nerita tessellata* has a peculiar color pattern of black and white checks, in which the white parts often are eroded, making a pattern of raised black blocks, interspersed with white grooves. In apertural features *N. funiculata* and *N. tessellata* are most alike, having more numerous denticulations on the outer lip, as many as 18, in contrast to about 12 in *N. fulgurans*.

Nerita tessellata and *N. fulgurans* are closely related but Russell, in his study of the western Atlantic nerites, observed that "the aperture is wider in relation to its length in *N. fulgurans* and the columellar teeth are more prominent" (1941, p. 364). Although they are indistinct in the Gatun specimen, the parietal teeth do more nearly resemble those of *N. fulgurans* (here figured, pl. 1, fig. 3) than those of *N. tessellata*, which are often no more then small rounded pustules.

However, externally, the fossil shell with its heavy spiral cords bears no resemblance whatsoever to the American species, its nearest relative being, as noted above, the Philippine *N. exuvia*. Due to the limited amount of material available the limits of variability cannot be ascertained. The type specimen has 12 spiral cords; the Panama specimen has only 11. In the living *N. exuvia* the number of cords ranges from 13 to 15, with new cords added by intercalation as the shell gets larger. Not surprisingly the color pattern of the fossil (as typical of Archeogastropoda, still visible) is also similar to that of *N. exuvia*, the common name of which is the "snake-skin* nerite" in reference to the color pattern of black and white zigzags that mark the shell.

The strong resemblance of the American fossil to the living Indo-Pacific species is not to be taken as indicating any remarkable trans-Pacific contacts, but rather as descent from a common ancestor far back in the Tertiary. In the early Miocene we see a similar form in *N. plutonis* Basterot, 1825, from the Aquitanian to Helvetian of

**exuvia* is Latin for a cast-off skin, as in a snake.

Europe. Even farther back, there is *N. caronis* Brongniart, 1823, from the Tongrian, which is also (as best can be ascertained from the illustrations, at least) similar. The genus *Nerita* has an extended geological history dating back into the Mesozoic and, thus, it is not surprising to find these disjunct remnants.

The exact age of the fossil species is somewhat uncertain. Trechmann described *N. exuvioides* from the tuffaceous beds at Point Saint Hilaire, Carriacou, assigning a lower Pliocene age. This age has been followed by most subsequent authors and would correlate with the occurrence in the Gatun Formation, also believed to be lower Pliocene in age.

However, in 1972, Robinson and Jung described the stratigraphy of Carriacou and named a new Grand Bay Formation. According to these authors, the age of the Grand Bay at the type locality, as determined by foraminiferal assemblages is N.9 to N.11 (or early middle Miocene). On the basis of conspecificity of mollusk species they concluded that the Saint Hilaire beds are the same age, noting that the differences in the two faunas can be accounted for by assuming facies control. According to Jung (1971, p. 153) in the total Grand Bay Formation (as considered by Robinson and Jung) there are 109 molluscan species, of which 39% occur in the typical sandy facies, 29% are confined to the tuffaceous beds, and 32% are found in both facies. These figures are not so compelling to remove any question about the correlation.

As Jung notes (*ibid.*, p. 160) the problems of correlation utilizing the macrofauna of the Grand Bay Formation with other faunas in the Caribbean is hindered by the poor preservation of the Carriacou fauna. Therefore, no conclusion is possible, but it is worth noting the possibility of a younger age for the tuffaceous beds. On the other hand, the presumed ancestral species in Europe have a long geologic range and it is entirely reasonable that the species ranges from the early middle Miocene into the lower Pliocene — that is, after all, only about ten million years, less than the range of *N. plutonis*.

Genus NERITA Linnaeus, 1758

Nerita LINNAEUS, 1758, Syst. Nat., ed. 10, p. 776.

Type species: *Nerita peloronta* Linnaeus, 1758 (sub. des., Montfort, 1810).

Subgenus THELIOSTYLA Mörch, 1852

Theliostyla MÖRCH, 1852, Cat. Yoldi, pt. 1, p. 167.

Type species: *Nerita albicilla* Linnaeus, 1758 (sub. des., Kobelt, 1879).

NERITA (THELIOSTYLA) EXUVIOIDES Trechmann

Nerita exuvioides TRECHMANN, 1935, Geol. Mag., v. 72, no. 12 (No. 858), p. 551, pl. 20, fig. 30.

NOT *Nerita (Nerita) exuvioides* ? Trechmann. JUNG, 1969, Bulls. Amer. Paleontology, v. 55, no. 247, p. 424, pl. 42, figs. 12, 13 [? = *N. fulgurans* Gmelin].

Nerita (Nerita?) exuvioides Trechmann. JUNG, 1971, Bulls. Amer. Paleontology, v. 61, no. 269, p. 175, pl. 6, figs. 1,2 (holotype).

Description: "Shell thick with spire depressed, the last whorl large and inflated. Decoration on the body-whorl consists of twelve rounded spiral ridges with hollow interspaces rather wider than

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PLATE 1

Figures

1. *Nerita (Theliostyla) exuvioides* Trechmann (×1½)
   USNM 365135; height 28.5 mm, diameter 33.0 mm
   Locality: TU 1432. Gatun Formation, Panama
2. *Nerita (Theliostyla) exuvia* Linnaeus.(× 2)
   USNM 819922; height 22.5 mm, diameter 25.9 mm
   Locality: Mambajao, Camiguin Isl., Philippine Islands
3. *Nerita (Theliostyla) fulgurans* Gmelin (×1½)
   USNM 819923; height 32.5 mm, diameter 30.2 mm
   Locality: TU R-215, Kingston, Jamaica

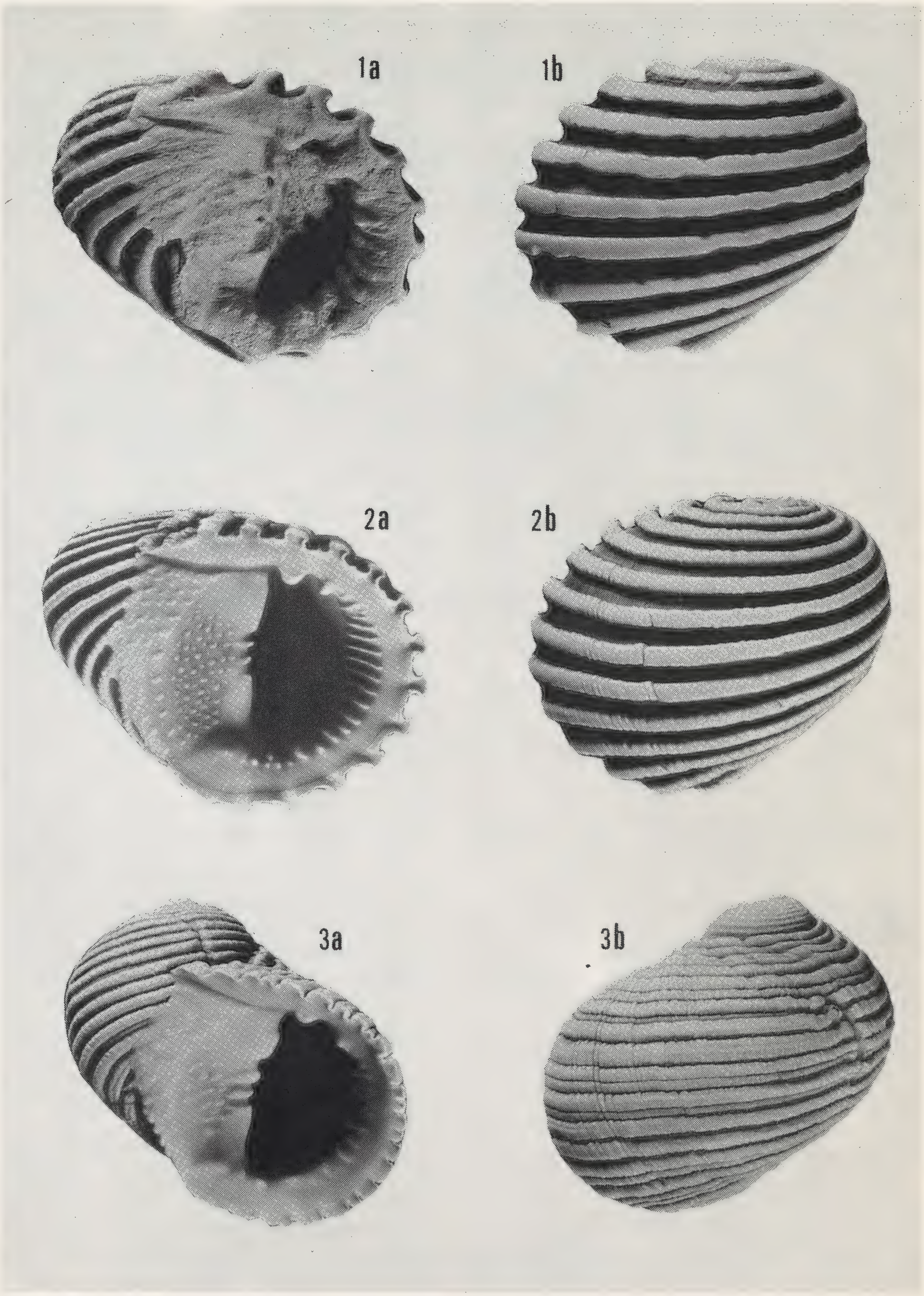

PLATE 1

the ridges, the sides of each ridge tending to overhang the intervening space; there are no intercalated ribs. The inner lip slopes steeply down into the aperture and is papillated and apparently bluntly toothed. The shell is damaged at the apex and the edge of the inner lip cannot be well seen." (Trechmann, 1935)

Holotype: British Museum (Natural History), Dept. Paleontology no. GG 4503.

Dimensions of holotype: height 22.5 mm, diameter 27.2 mm (*fide* Jung, 1971, p. 175).

Type locality: "St. Helene Point" (= Point Saint Hilaire), Carriacou, Grenadines.

Figured specimen: USNM 365135; height 28.5 mm, diameter 33.0 mm; locality TU 1432, Gatun Formation, Panamá.

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TRECHMANN, C. T., 1935, The geology and fossils of Carriacou, West Indies: Geol. Mag., v. 72, no. 12 (No. 858), p. 528-555, pls. 20-22.

LOCALITY DATA

1432. Gatun Fm., north side Boyd-Roosevelt Highway, clearing behind Residential Martin Luther King (former Palo Quemado), approximately 1.5 km east of junction of road to "Refinería Panamá, S. A.," at Cativá, Prov. of Colón, Panamá.

R-215. Mangrove swamp between Palisados Airport and road to Port Royal, Kingston, Jamaica.

December 29, 1983

REVIEW

ADAM SEDGWICK: Geologist and Dalesman, 1785-1873; a Biography in Twelve Themes, by Colin Speakman. Published jointly by The Broad Oak Press Limited, The Geological Society of London, and Trinity College, Cambridge, 1982, xii + 145 pp., 18 figs., paper $15.00

This volume comprises a series of twelve essays on various aspects of Sedgwick's life, his forebears, his academic and scientific life, his association with Murchison followed by the crisis of the Cambrian-Silurian Controversy, his association with Charles Darwin followed by his confrontation with Darwin's *Origin of Species,* his association with Prince Albert and Queen Victoria, and his later years. They present additional insight into Sedgwick as a man and the significance of his scientific influence and accomplishments.

After receiving from Darwin, a copy of the *Origin,* Sedgwick responded that he read it with "more pain than pleasure" and "parts I read with absolute sorrow, because I think them utterly false and mischievous." Darwin was deeply hurt by Sedgwick's "severe disapprobation and ridicule" and replied: "I do not think my book will be mischievous; for there are so many works that, if I be wrong, I shall soon be annihilated; and surely you will agree that truth can be known only by rising victorious from every attack." Sedgwick had been deeply offended by Robert Chambers's *The Vestiges of the Natural History of Creation* (1844) and he attacked this work indignantly at every opportunity. He viewed the *Origin* as another *Vestiges,* but "more expert and, therefore, more dangerous." Speakman states that Sedgwick "was, in fact, because of his honesty, integrity and fine scientific mind perhaps the most serious antagonist of the *Origin.*"

This collection of essays, as the foregoing example shows, helps to bring Sedgwick "to life" and demonstrate his prominence as a central figure in the development of geology as a scientific discipline during the "Heroic Age of Geology" and his contributions to the study and teaching of the geosciences.

—H.C.S.

ON THE OCCURRENCE OF *MILTHA (EOMILTHA) MEGAMERIS* (DALL) IN THE DOMINICAN REPUBLIC

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In the summer of 1982, while we were working on the Paleontology and Geology of the Cibao Valley area of the northwestern section of the Dominican Republic, Mrs. Vokes collected six paired-valve internal molds of an exceedingly large lucinid bivalve that prove upon examination to be referable to *"Lucina" megameris* Dall, 1901, described from the late Eocene of Jamaica. The present specimens were found in a conglomerate zone immediately north of the crest of the Cordillera Septentrional at Puerto de los Hidalgos on the west side of the Mao-Los Hidalgos road (TU 1424 — see text fig. 1). Limestone boulders in the conglomerate contain abundant foraminifera, including *Lepidocyclina* and *Discocyclina*, similar to those listed by Bermudez (1949, p. 11) from the strata that he "tentatively termed" the Hidalgos Formation, referring it to the middle Eocene. However, the boulders in the outcrop at TU 1424 clearly were completely lithified prior to their erosion and redeposition, suggesting a post-middle Eocene age for these strata in which they presently occur.

Family LUCINIDAE Fleming, 1828
Subfamily MILTHINAE Chavan, 1969
Genus MILTHA Adams and Adams, 1857

Miltha ADAMS and ADAMS, 1857, Genera of Recent Mollusca, v. 2, p. 468.

Type species, by monotypy, *Lucina childrenae* Gray, 1825. Recent, northeastern Brazil southward to off Bahia (Rios, 1975, p. 217).

Subgenus EOMILTHA Cossmann, 1912

Eomiltha COSSMANN, 1912, *in* COSSMANN and PEYROT, Actes Soc. Linn. Bordeaux, v. 65, p. 269.

Type species, by original designation, *Lucina contorta* Defrance, 1823, Thanetian Stage, Paleocene, France.

MILTHA (EOMILTHA) MEGAMERIS (Dall)
Plate 1, Figures 1-3

Lucina megameris DALL, 1901, Nautilus, v. 15, p. 40 (Eocene, "Clairmont" [*sic* = Claremont], St. Ann's Parish, Jamaica).

Phacoides (Pseudomiltha ?) megameris (Dall). DALL, 1901, U. S. Natl. Mus., Proc., v. 23, no. 1237, p. 829, pl. 42, fig. 1.

Lucina (Pseudomiltha) sp. TRECHMANN, 1923, Geol. Mag., v. 60, (no. 710), p. 361, pl. 14, fig. 5 (Chapelton Fm., Yellow Limestone Gr., Spring Mount, western Jamaica).

Pseudomiltha haitensis WOODRING and MANSFIELD, 1924, *in* WOODRING, BROWN and BURBANK, Geology Republic of Haiti, p. 612, pl. 10, fig. 1 (Plaisance Limestone, middle Eocene, Haiti).

Phacoides (Pseudomiltha) megameris (Dall). COX, 1941, Malac. Soc. London, Proc., v. 24, pt. 4, p. 136, pl. 9, fig. 1 (White Limestone, "about top of the upper Eocene," Jamaica).

Pseudomiltha ? cf. *haitensis* Woodring and Mansfield. WOODRING and DAVIESS, 1944, U. S. Geol. Surv., Bull. 935-G, p. 373 (Charco Redondo Limestone, early upper Eocene, Oriente Prov., Cuba).

Pseudomiltha cf. *megameris* [Dall]. WOODRING and THOMPSON, 1949, Amer. Assoc. Petrol. Geol., Bull., v. 33, no. 2, p. 228 (Gatuncillo Fm., late Eocene, Madden Basin, Panamá).

Pseudomiltha megameris Dall. RICHARDS, 1953, *in* RICHARDS and PALMER, Florida Geol. Surv., Bull. 35, p. 48, pl. 10, fig. 6 (Eocene, Avon Park Limestone, and Inglis Memb., Moodys, Branch Fm.; Citrus and Levy counties, Florida).

Phacoides megameris [Dall]. HOSE and VERSEY, 1956, Colonial Geol. and Min. Res., v. 6, no. 1 (a fossil bank in Gibraltar Limestone member of White Limestone, on northern flank of Jamaica, characterized by abundant *Phacoides megameris*).

Pseudomiltha megameris Dall, PALMER and BRANN, 1965, Bulls. Amer. Paleontology, v. 48, no. 218, p. 284 (USNM specimen no. 147592 designated as lectotype).

Pseudomiltha megameris (Dall). JUNG, 1972, VI Conf. Geol. del Caribe, Mem., p. 466 ("abundant and characteristic of Claremont Formation," White Limestone Gr., Jamaica).

Pseudomiltha megameris (Dall). JUNG, 1974, Verhandl. Naturf. Ges., Basel, v. 84, no. 1, p. 493 (Ceru di Cueba Fm., "middle or late Eocene age," Curaçao; "another similar or even conspecific form occurs in the middle Eocene St. Bartholomew Formation," island of St. Bartholomew).

Miltha (Eomiltha ?) megameris (Dall). BRETZKY, 1976, Palaeont. Americana, v. 8, no. 50,

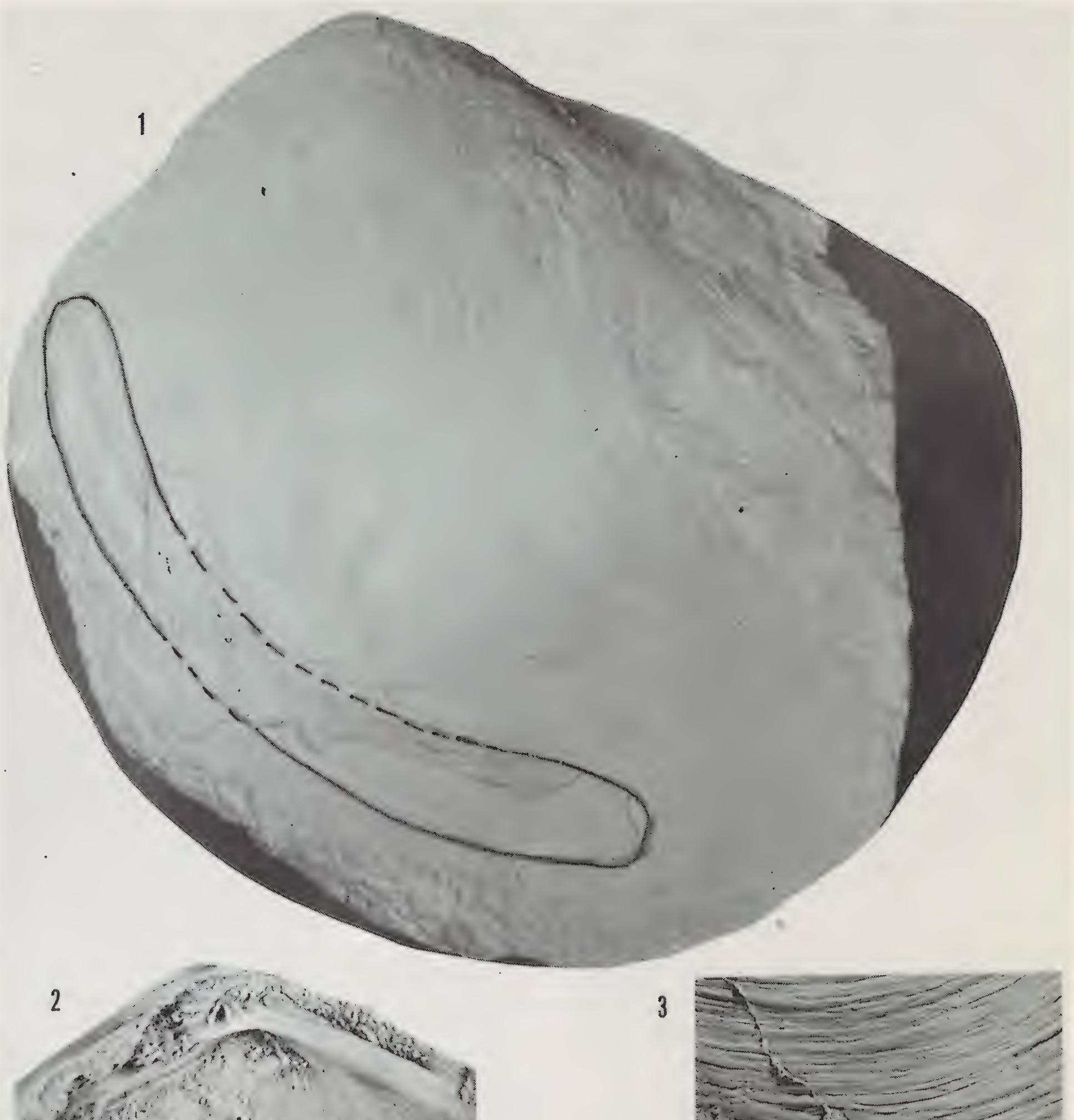
Text figure 1. View of outcrop at TU locality 1424, Puerto de los Hidalgos on west side of Mao-Los Hidaglos road, Dominican Republic.

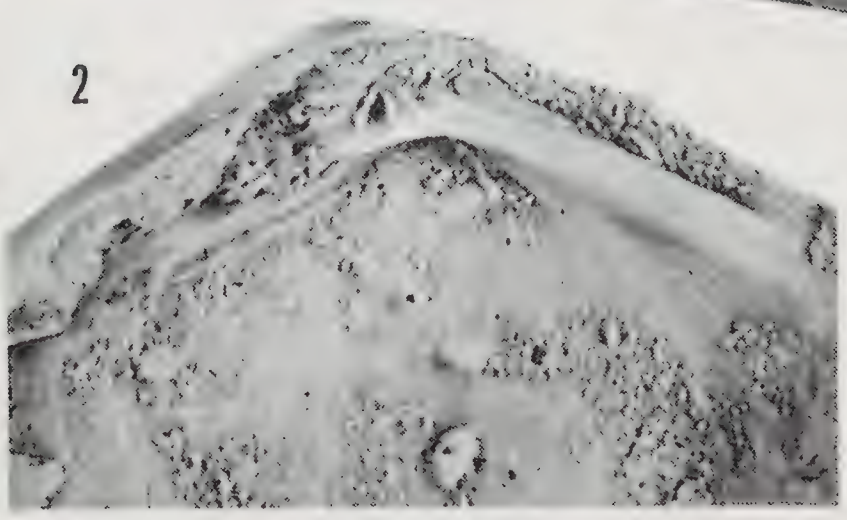
pp. 239, 290 ("may be an *Eomiltha*, . . . has the characteristic long, curved anterior adductor scar . . .").

Pseudomiltha megameris (Dall). WOODRING, 1982, U. S. Geol. Surv., Prof. Paper 306-F, p. 620, pl. 88, fig. 1 (Gatuncillo Fm., late Eocene, Madden Basin, Panamá).

Discussion: Miltha (Eomiltha) megameris (Dall), the largest known lucinid species, described from Jamaica in 1901 as *"Lucina,"* but almost immediately (also in 1901) provisionally referred to *Phacoides (Pseudomiltha ?)*, has been assigned almost universally to *Pseudomiltha* Fischer, 1887 (type species, by monotypy, *Lucina gigantea* Deshayes; Eocene, Paris Basin, France). *Pseudomiltha gigantea* is, however, an edentulous species, but essentially topotype specimens of *M. megameris* in the Tulane University collections (TU 1006) show evidence suggestive of weak cardinal teeth, and molds of others from the Inglis Formation of Florida (TU 778) reveal a right valve hinge that is marked by a small and slender anterior cardinal and a broader, bifid, posterior one (pl. 1, fig. 2). This type of hinge, plus the presence of the extremely long and curved anterior adductor scar strongly supports Bretzky's (1976, pp. 239, 290) suggestion that it "may be an *Eomiltha.*"

It seems probable that a misinterpretation of Olsson's (1932, p. 94) statement, "*Phacoides (Pseudomiltha ?) megameris* Dall from Jamaica, which is probably not a true *Pseudomiltha*, is nearly twice as large and much heavier" than "large specimens





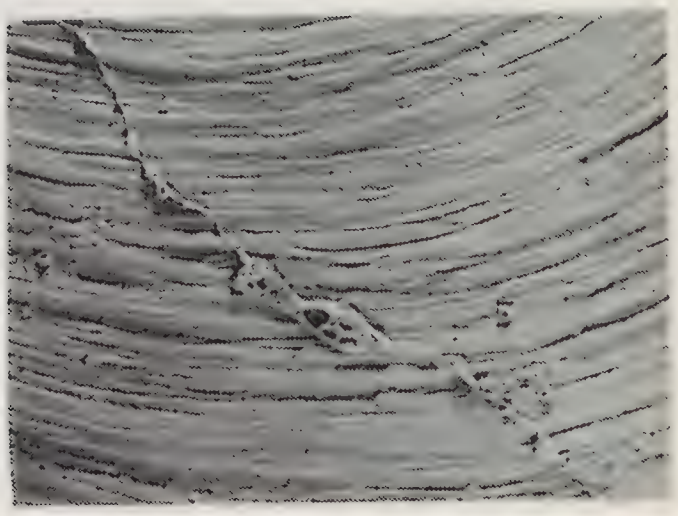


PLATE 1

Miltha (Eomiltha) megameris (Dall)

Figures

1. (× 0.6) largest specimen from the Dominican Republic (max. dimension 200 mm); marginal extensions to show approximate original shape of internal cast. Anterior adductor scar outlined showing its similarity to that of species of *Eomiltha;* dashed areas where scar is partially covered by worn remnants of shell. Locality TU 1424.
2. (× 1) Latex cast of hinge area of small specimen from the Inglis Formation, upper Eocene; locality TU 778, Inglis, Florida.
3. (× 1) Latex cast of piece of an external mold, showing surface ornament of shell; locality TU 1006, Claremont, Jamaica.

of *Zorrita* from the lower Miocene beds of Ecuador [which] have a length of 120 millimeters" is responsible for Chavan's statement (1969, p. N504) that *Zorrita* has a range: "*Eoc.-Mio.*, Peru-Jamaica-Eu." It is also to be noted that Olsson says, in his description of the type species of *Zorrita* (p. 95): "hinge edentulous without cardinal and lateral teeth," but Chavan states "remnants of 3b and 4b present;" the basis for this statement is not known.

It is apparent that Woodring and Mansfield (1924, p. 613) overlooked Dall's description of the present species when they described their *Pseudomiltha haitensis*. They state: "no similar American species has been described, but the same or very similar species has been collected from the 'Yellow Limestone' of Jamaica. Dr. C. A. Matley, Government Geologist of Jamaica, recently brought to Washington specimens from the parishes of St. James and Trelawney. Most of the Jamaica specimens are internal casts and clearly show the long, narrow anterior muscle scar, but the hinge is obscure." Accordingly, that species is here considered a synonym of *M. megameris*.

In summary, *Miltha (Eomiltha) megameris* (Dall originally described from late middle or upper Eocene limestones at Claremont, Jamaica, has also been reported, in-so-far as a search of available literature has revealed, from limestones of the same general age in Florida, from Cuba and Hispaniola (Haiti and here the Dominican Republic) in the Greater Antilles, from the island of St. Bartholomew in the northern portion of the Leeward Islands group, from Curacao in the southernmost Lesser Antilles, and from Panamá (in the former Canal Zone).

LOCALITY DATA

778. Inglis Fm., Florida Barge Canal, at U. S. Highway 19, just south of Inglis, Florida.
1006. Claremont Fm., Claremont, Parish of St. Ann, quarry across from church on road to Moneague, Jamaica.
1424. Los Hidalgos Fm., roadcut at crest of ridge on highway from La Cruz de Guayacanes to Los Hidalgos, approximately 25 kms north of Mao, Dominican Republic.

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December 29, 1983

REVIEW

FROM RIFT TO DRIFT: Iowa's Story in Stone, by Jack Clayton Troeger. Published by Iowa State University Press, Ames, Iowa, 1983, x + 152 pp., illus., $14.95

This is intended as a "minicourse" in geology written in everyday conversational terms, describing the earth's materials and processes, geological time, and other fundamental aspects of geology. It traces Iowa's geological history from a "wrenching plate boundary" in its remote past to today's terrane, a relic from the Ice Age. It will be of interest to readers who have had no formal training in geology but who are interested in the past history of Iowa. It can be used as a text in earth science courses in the lower schools.

--H.C.S.

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